AGRONOMIC POTENTIAL OF BIOCHAR IN CONTRASTING MAIZE-BASED TEMPERATE AND TROPICAL AGRO-ECOLOGICAL ZONES

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ABSTRACT

Managing soil fertility is important to sustain both a productive agricultural economy and to preserve our natural environment. However, soil management practices will vary depending on the agro-ecosystem; agricultural soils in the temperate world often experience excess applied nutrients, while soils in the humid tropics often have a net negative nitrogen economy. Co-applications of organic amendments with synthetic fertilizers have been proposed to increase the efficiency of nutrient cycling and reduce nutrient losses in diverse agroecosystems. Soil applications of biochar may be an effective nutrient management technique with applications in both temperate and tropical cropping systems.

Biochar derived from maize stover was applied to a maize cropping system in central New York at rates of 0, 1, 3, 12, and 30 t ha^{-1} in 2007. Secondary nitrogen fertilizer applications were added in treatments consisting of 100, 90, 70, and 50% of the recommended rate. Nitrogen fertilizer enriched with ^{15}N was applied in 2009 to the treatment combinations of 0 and 12 t ha^{-1} of biochar and 100 and 50% secondary N application. Maize yield and plant N uptake did not change with any biochar treatment ($P>0.05$; $n=3$). However, significantly less N (by 75%) was lost through leaching at 100% N fertilization, albeit at low total losses of applied ^{15}N (0.42% of applied N). The reason for an observed 140% greater N retention in the topsoil may have been the incorporation of N into microbial biomass which increased 3-fold. The resulting total N recovery in the soil-plant system of 83% with the addition of biochar in comparison

to 61% without biochar after one cropping season may also indicate lower gaseous losses with biochar.

The residual effects of organic inputs of contrasting quality on maize productivity were investigated as a function of soil degradation in the highlands of western Kenya. Tithonia (*Tithonia diversifolia* (Hemsl.) A. Gray) green manure, cypress sawdust, and biochar made from eucalyptus wood were applied at a rate of 6 t C ha^{-1} for three cropping seasons, both with and without mineral fertilizer additions (120 kg N ha^{-1}, 100 kg K ha^{-1}, 100 kg P ha^{-1}). Maize grain yield was monitored for four years beyond the initial organic matter additions. The greatest yield responses for all amendments were found on the most degraded soil. During those years when amendments were added, tithonia applications resulted in the greatest yield increases, between 153 and 183% more than the unamended control in comparison to 136% with biochar and 107% with sawdust additions. However, four years after tithonia applications to highly degraded soils stopped, yields rapidly declined to only 110% of the unamended control, whereas yields after biochar additions remained constant at 0.3-1.8 t yr^{-1} or 9-265% greater than yields without organic amendments. Four years after organic matter additions ended, maize yields were not significantly different irrespective of additions of the quality of organic amendments. Even four years after organic matter additions, yields in response to fertilizer additions to highly degraded soils were 113% greater when applied together with the organic inputs than alone. No significant differences were found with or without fertilizer or organic matter additions in the farms recently converted from forest. The data indicate that yield responds in the short-term to input quality and specifically the amount of applied N; while the residual effects of organic matter additions on yield dynamics may relate more to input C quality and increasing soil C.

BIOGRAPHICAL SKETCH

David was born and raised in Santa Barbara, California. He received his Bachelors of Science degree from California Polytechnic State University in Soil Science and Crop Science. While attending university he became involved in organic and alternative farming systems. While there he worked for three years at the Cal Poly Organic Farm under the supervision of master farmer, Jerry Mahoney. David began his graduate program in Soil Science at Cornell University in 2008 under the supervision of Dr. Johannes Lehmann. For his masters work David focused on the use of biochar as a soil fertility amendment in upstate New York and in the equatorial highlands of western Kenya. David is married to Bethany Guerena. They have one child, Levi Thomas Guerena.

This thesis is dedicated to my father, Salvador Guerena. He taught me from an early age to appreciate and value the natural world. To his guidance I am greatly indebted.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

NITROGEN DYNAMICS FOLLOWING FIELD APPLICATION OF BIOCHAR IN A TEMPERATE NORTH AMERICAN MAIZE-BASED PRODUCTION SYSTEM

Abstract

Biochar additions to tropical soils have been shown to reduce N leaching and increase N use efficiency. No studies exist testing this trend in temperate agricultural soils or identifying the mechanism for retention. Biochar derived from maize stover was applied to a maize cropping system in central New York at rates of 0, 1, 3, 12, and 30 t ha^{-1} in 2007. Nitrogen side dress was added in treatments consisting of 100, 90, 70, and 50% of the recommended rate. Nitrogen fertilizer enriched with ^{15}N was applied in 2009 to the treatment combinations of 0 and 12 t ha^{-1} of biochar and 100 and 50% secondary N application. Maize yield and plant N uptake did not change with any biochar treatment (p>0.05; n=3). However, less N (by 82%; p<0.05) was lost after biochar application through leaching at 100% N fertilization, albeit at low total losses of applied ^{15}N (0.42% of applied N). The reason for an observed 140% greater total N retention in the topsoil may have been the incorporation of applied ^{15}N into microbial biomass which increased approximately three-fold (p<0.1). The resulting total N recovery in the soil-plant system of 83% with the addition of biochar in comparison to 61% without biochar (p=0.1) after one cropping season may also indicate lower gaseous losses with biochar. Addition of biochar to fertile soil in a temperate climate did not improve crop growth, but increased retention of fertilizer N in the plant-soil system.

Introduction

Agriculture is a major contributor to terrestrial anthropogenic nitrogen (N) pollution and has resulted in profound ecological changes (Vitousek et al. 1997). Nitrogen losses to the environment from intensive agricultural production has consequently led to both direct and indirect negative feedbacks to environmental and human health. These effects occur in agricultural production systems in developed and developing countries and in tropical and temperate ecosystems (Townsend et al. 2003).

Nitrogen loading in waterways through leaching of nitrate (NO_3^-) from agricultural fields contributes to eutrophication of rivers, lakes, and oceans (Burkholder 1998; Mitsch et al. 2001). In addition, pervasive groundwater NO_3^- contamination poses a threat to human health and has been correlated to fertilizer use in both developed and developing countries (Agrawal et al. 1999; Mitsch et al. 2001; Oenema et al. 1998; Randal et al. 1997). Leaching losses of NO_3^- have been found to be highest for maize-based cropping systems (Owens 1990; van Es et al. 2006) and can represent small (Sogbedji et al. 2000) to large (Cahn et al. 1993) losses of applied fertilizer N. These losses of N represent inherent inefficiencies in current nutrient management and result not only in environmental pollution but additional economic cost to farmers and land managers.

Various methods have been proposed to improve fertilizer N use efficiencies and limit N losses to the environment. These methods include limiting N fertilizer usage (Francis et al. 1992), switching to perennial-based agricultural systems (Drinkwater et al. 1998), or applying nitrification inhibiting chemicals to reduce the amount of mobile NO_3^- in the soil (Walters and Malzer 1990). Limited work has been done to improve fertilizer N use efficiency through greater retention of N in the soil. Applications of biochar (BC) could be one mechanism to improve N retention and reduce N leaching (Lehmann 2007b).

Several mechanisms may control N retention in biochar. Biochar may retain ammonium through increases in soil cation exchange capacity (CEC) (Liang et al. 2006) and changes in soil pH (Chan et al. 2008; Matsubara et al. 2002; Novak et al. 2009). Indeed, ammonium retention has been shown to occur after biochar additions to an Oxisol (Lehmann et al. 2003). Biochar could also alter soil water percolation through changes in pore-size distribution, soil solution residence times, and flow paths (Major et al. 2009) for which experimental evidence is still lacking. Changes in soil microbial community composition have been found in biochar-rich soils (O'Neill et al. 2009; Grossman 2010); these changes could alter microbial mediated N dynamics including nitrification (DeLuca et al. 2006). Steiner et al. (2008) found significantly greater residual fertilizer N in the soil following application of biochar. The authors attributed the difference to increased N recycling through the above-ground biomass, and possibly reduced leaching and gaseous losses, immobilization of N by microbial biomass, or retention of ammonium (NH_4^+) on the cation exchange sites as possible explanations. The retention of other cations as well as improvements in soil fertility in general, may have increased N uptake (Lehmann et al. 2003; Major et al. 2010; Haefele et al. 2011) and hence reduced N leaching.

While biochar studies on soil fertility and agronomic effects have increased in recent years most of the work has been done in tropical cropping systems (Chan et al. 2007; Steiner et al. 2007; Steiner et al. 2008; Kimetu et al. 2008; Hidetoshi et al. 2009; Gaskin et al. 2010; Major et al. 2010; Van Zwieten et al. 2010; Haefele et al. 2011). Very few studies exist documenting the soil fertility (Novack et al. 2009; Laird et al. 2010a) and yield effects (Vaccari et al. 2011) of biochar in temperate cropping systems and only one published study for a tropical agroecosystem could be found that quantify N leaching losses in the field (Major et al. 2011). The increased yields commonly reported in highly weathered and acid tropical soils have frequently been attributed to increases in pH, CEC and nutrient retention (Lehmann et al. 2003; Van Zwieten et al. 2010a). However, in many soils currently under production in temperate climates, CEC and pH are typically not limiting crop productivity. The management problem in temperate cropping systems is rather an excess of applied nutrients, the opposite problem of agricultural systems in the tropics. Some studies have found lower N leaching after biochar additions in both greenhouse and field experiments (Lehmann et al. 2003; Laird et al. 2010b; Major et al., 2011). Other indications exist that these leaching reductions may result in improved N use efficiency hypothesized for tropical soils (Chan et al. 2007; Steiner et al. 2008). Therefore, the potential may exist to increase soil N retention and N use efficiency in temperate soils, thereby maintaining yields even with lower N applications.

A long-term experiment was established in a temperate maize cropping system in central New York to evaluate the effect of biochar applications on crop yields, N leaching, and fertilizer N use efficiency using ^{15}N as a tracer. The specific objectives of the experiment were to: (1) evaluate the effect of increasing rates of biochar application on maize grain yield; (2) determine the efficacy of biochar applications to maintain maize grain yield with reductions in N fertilizer applications; (3) quantify the effects of biochar additions on in-situ leaching losses of fertilizer N over one year.

Methods

Field site

The field experiment was established at the Cornell University Musgrave Research Farm in Aurora, NY (42°43’48.64”N, 76°39’16.03”W). The climate is humid continental, with a mean annual rainfall of 940 mm, and a mean maximum temperature of 14°C and a mean minimum temperature of 4°C. The mean growing degree days are 2400 (GDD, 86-50° system). The soils are classified as a Junius loam (0-2% slopes, overtill), Kendaia silt loam (2-5% slopes) and Lima loam (2-6% slopes), or fine-loamy, mixed, mesic Glossoboric Hapludalf. The studied soil has a pH of 6.85 in 1N KCl (ratio of 1:20 w/v), a bulk density of 1.29 g cm^{-3}, CEC of 97.6 $mmol_c$ kg^{-1}, particle size distribution of 27% clay, 31% silt and 42% sand, total C content of 16.2 mg g^{-1}, total N of 1.62 mg g^{-1}, and Mehlich-3 extractable P of 35.8 mg kg^{-1}, K of 84.1 mg kg^{-1}, Ca of 3739 mg kg^{-1}, Mg of 483 mg kg^{-1} and Na of 75 mg kg^{-1}.

Biochar

Maize stover from a commercial farm in New South Wales, Australia, was oven dried to approximately 10% moisture before pyrolysis. Biochar was produced at approximately 600°C using slow pyrolysis in a continuous system with an average residence time of about 30 min with relatively high air purge (Pyrochar 300; BEST Energies, Somersby, Australia). The biochar had the following properties: pH (KCl) 10.02; ash 64%; volatiles 26%; fixed carbon 10%; total C 290 mg g^{-1}; C/N ratio 96; total P 0.41 mg g^{-1} (additional data in supplementary online material). The biochar was stored moist for three months before application.

Experimental setup

Prior to the experiment the field was planted to continuous maize for over 30 years. The research area was split into 33 plots with a size of 4.5 by 7.5 m (33.75 m^2 per plot). Two meter buffer zones were established between plots on all sides. In April 2007, biochar was applied once at rates of 0, 3, 12, and 30 t ha^{-1} (Table 1). An additional treatment consisted of annual applications of 1 t ha^{-1}. This biochar applied annually was from the same batch of the other treatments. It was stored moist until application. This treatment was applied for the 2007, 2008, and 2010 growing seasons, but not in 2009. All biochar applications were incorporated by a hand rake followed by a disc plow.

Each year, fields were chisel plowed, followed by disc plowing before planting. Maize (Dyna-Gro Yieldgard hybrid seed, Crop Production Services, Loveland, CO) was planted at a rate of 79,040 seeds ha^{-1}, with 0.4 m distance within rows that were 1.2 m apart, between May 11 and 20, depending on weather conditions in each year. At planting, atrazine was sprayed at 1 L ha^{-1} and a mixture of S-Metolachlor, atrazine and mesotrione (Lumax®, Syngenta, Basel, Switzerland) at 5 L ha^{-1}. Following emergence of the corn plants, post-emergent herbicides ricosulfuron/rimsulfuron (Steadfast®, DuPont, Wilmington, DE) and diglycolamine (Banvel®, DuPont, Wilmington, DE) were applied at rates of 52.5 g ha^{-1} and 140 g ha^{-1}, respectively.

Table 1.1 Experimental design. All treatment combinations were established in three replicates (*n*=3).

	Fertilization (% of full recommended fertilization)			
Biochar (t ha^{-1})	50	70	90	100
0	X	X	X	X
3			X	
12	X	X	X	X
30			X	
1 (annually)			X	

A 10-10-20 granular fertilizer was applied at the rate of 123.5 kg ha^{-1} (12.35 kg N ha^{-1}; 5.43 kg P ha^{-1}; 20.51 kg K ha^{-1}) at planting for all plots for all planting years. Secondary N fertilizer was applied approximately six weeks after planting. The standard recommended secondary N fertilizer application rate for the area is 107.61 kg N ha^{-1}. Plots at each application rate of biochar (including the control without biochar) received 90% (96.85 kg N ha^{-1}) of the recommended secondary N fertilizer application rate in order to investigate the effect of biochar application rate on grain yield. For the 0 and 12 t BC ha^{-1} application rates, additional treatments with varying amounts of secondary N fertilizer application rates at 50% (53.81 kg N ha^{-1}), 70% (75.33 kg N ha^{-1}), and 100% (107.61 kg N ha^{-1}) of the recommended rate were included. All treatments were replicated three times in a completely randomized design.

Lysimeters

In the spring of 2009, before the field was tilled or planted, free-draining lysimeters were installed in each of three replicate plots that received 50 or 100% secondary N fertilizer application rates for both 0 and 12 t biochar ha^{-1} application rates. One lysimeter was installed per plot. Rectangular lysimeters were manufactured from stainless steel and filled with acid-washed quartz sand. The dimensions of the lysimeters that interfaced with the soil surface were 101.6 mm by 304.8 mm, with a depth of 101.6 mm. In April 2009 vertical holes were dug in the inter-row spaces bordering the aforementioned plots. Lateral holes were dug into the soil beneath the targeted plots and the lysimeters were installed with each uppermost surface being approximately 0.6 m below the soil surface. The lysimeters were connected to a glass collection bottle placed in the bottom of the vertical pit via PVC tubing (VWR Signature Tubing, VWR, Batavia, Il). Two PVC evacuation tubes were also installed into the collection bottles that connected to the soil surface to allow the leachate to be collected via vacuum. After the instillation was completed the entire pit was backfilled with soil leaving the evacuation tubes exposed.

Isotopic labeling

In July of 2009, secondary N fertilizer application in plots that received 50 or 100% fertilization at 0 and 12 t biochar ha^{-1} was combined with an application of ^{15}N isotope enriched NH_4NO_3 at 10 atom% ^{15}N with the isotopic label on both the NH_4-N and NO_3-N. The ^{15}N was applied to sub-plots of 6.02 by 2.78 m (16.74 m^2) within the chosen treatment combinations. ^{15}N with the labeled fertilizer was applied at the rate of 1 kg ^{15}N ha^{-1} or total N of 10 kg ha^{-1}, which replaced the equivalent amount of non-labeled N to maintain uniformity in the total amount of N applied within treatments. The isotopically labeled fertilizer was mixed with the normal NH_4NO_3 fertilizer in individual containers for each plot. The fertilizer was completely dissolved in water and applied to the moist soil by hand pipettes.

Lysimeter sampling and analysis

All lysimeter collection bottles were completely evacuated into acid-washed glass bottles following each significant rain event for the entire 2009 growing season from 4 June to 17 October, in weekly intervals. After evacuation, 10 mL of toluene was injected back into the buried collection bottles as a biocide agent to minimize microbial transformation of N. The samples were immediately transported to the laboratory at Cornell University and total leachate volume was determined. Two subsamples were collected for each lysimeter from each leaching event and immediately placed in refrigeration. One set of subsamples was analyzed for NH_4^+, NO_2^-, and NO_3^- colorimetrically using a continuous flow analyzer (Bran and Luebbe

Autoanalyzer, SPX, Charlotte, NC). A second 20-mL subsample was freeze-dried (Dura-Dry^{tm} μP, FTS Systems Inc., Stone Ridge, NY) and analyzed for total ^{15}N by isotope ratio mass spectrometry (PDZ Europa ANCA-GSL elemental analyzer, PDZ Europa 20-20 isotope ratio mass spectrometer, Sercon Ltd., Cheshire, UK).

Soil sampling and analysis

Representative soil samples were taken in 0.1-m increments from the surface to a depth of 0.6 m from all plots that received ^{15}N. Soil samples were taken from the field in the spring of 2009 prior to planting and ^{15}N application as well as just after harvest in the Fall of 2009. Soil, plant, and leachate samples taken prior to ^{15}N application were used as the reference natural abundance values for ^{15}N analysis. Exchangeable NO_3^- and NH_4^+ were extracted from 10 g oven-dry soil taken in fall with 100 mL 2N KCl for one hour (Mulvaney 1996). Nitrate, NO_2^-, and NH_4^+ in all soil extracts were quantified colorimetrically using a continuous flow analyzer (Bran and Luebbe Autoanalyzer, SPX, Charlotte, NC). The soil samples were air-dried and passed through a 2-mm sieve. A sub-sample of the sieved soil was finely ground for total ^{15}N. Total ^{15}N was determined by isotope ratio mass spectrometry (PDZ Europa ANCA-GSL elemental analyzer, PDZ Europa 20-20 isotope ratio mass spectrometer, Sercon Ltd., Cheshire, UK).

Microbial biomass N and N mineralization potential were quantified from a sub-sample of air-dried and sieved soil taken after harvest. The chloroform fumigation method was used to determine microbial biomass N (Witt et al., 2000) following a 12-hour incubation at room temperature wetted to field capacity. Final microbial biomass N was adjusted to normalize for differential soil and biochar adsorption of lysed cells using adsorption isotherms following the method by Jin (2010). This correction recognizes the stronger adsorption of dissolved organic matter to biochar than soil (Liang et al. 2010; Lehmann et al. 2011). A DON stock solution for the isotherms was prepared by shaking 400 g of soil taken from the topsoil (0-0.1 m) adjacent to the experimental area in October 2009 with 1000 mL of deionized water overnight. The dissolved total N concentration of the extract was determined by a total DOC/DON analyzer (Shimadzu TOC-5000a Autoanalyzer, Columbia, MD, USA). Mineral N values for these samples were determined by a continuous flow analyzer (Bran and Luebbe Autoanalyzer, SPX, Charlotte, NC). Dissolved organic N was then determined by subtracting the mineral N values from the total dissolved N values. Fourty milliliters of DON stock solution was added at nine concentrations (5, 10, 15, 20, 30, 40, 60, 80 and 100 μg ml^{-1}) to 10 g (oven-dry weight) soil from each treatment and shaken for 12 hours. The mixture was then centrifuged at 10,000 x g. The supernatant was extracted and analyzed with a TON/TOC analyzer (Shimadzu TOC-5000A Autoanalyzer). These values were used to determine the sorption coefficient following the Freundlich equation (Eq. 1):

$$S = K \cdot C_e^n \qquad (1)$$

whereby S is the amount adsorbed at equilibrium (μg g^{-1} soil), C_e is the equilibrium concentration of the adsorbate (DON), and K and n are the Freundlich constants, n giving an indication of how favorable the adsorption process is and K is the adsorption capacity of the adsorbant and represents the quantity of DON adsorbed for a unit equilibrium concentration.

Total microbial biomass N and ^{15}N was determined in dried extracts (modified after Bruulsema and Duxbury 1996) by isotope mass spectrometry (PDZ Europa ANCA-GSL elemental analyzer, PDZ Europa 20-20 isotope ratio mass spectrometer, Sercon Ltd., Cheshire, UK).

Nitrogen mineralization potential was determined following Campbell et al. (1993) with the following modifications. Buchner funnels were used in place of leaching tubes, which received a glass fiber filter over the funnel plate, followed by glass wool, the sand/soil mixture, and a final portion of glass wool over the soil to allow leaching of accumulated N with minimal disturbance of the soil. The funnels were covered with two layers of parafilm to prevent desiccation of the soil. The soil was incubated at 30°C between extractions with 100 mL of 0.01 M $CaCl_2$ and addition of 25 mL of a non-N nutrient solution (0.002 M $CaSO_4$, 0.002 M $MgSO_4$, 0.005 M $Ca(H_2PO_4)_2$, and 0.0025 M K_2SO_4) at day 2, 5, 10, 20, and 30.

Bulk density was determined with 0.1-m^3 rings using three measurements per plot at the center of each depth increment from the soil surface to 0.6 m in 0.1-m increments.

Harvest and plant sampling

In the Fall, maize grain and stover yields were determined from the same 16.74-m^2 sub-plots that were used for ^{15}N application. Total number of cobs and total wet biomass and grain weight for the sub-plot was determined in the field. Five plants and ten cobs were randomly selected from each of the subplots and were dried to constant weight at 60°C to determine moisture content. The dried grain was removed from the cob and used to determine grain yield. A composited sub-sample of all plant parts was finely ground to determine total above ground N recovery. Total N and ^{15}N was determined by isotope ratio mass spectrometry (PDZ Europa ANCA-GSL elemental analyzer, PDZ Europa 20-20 isotope ratio mass spectrometer, Sercon Ltd., Cheshire, UK).

Calculation of fertilizer derived nitrogen

Fertilizer derived N was determined using Eq. 2:

$$\left([^{15}N_f]-[^{15}N_r]\right)/\left(^{15}N_i \times N_t\right) \qquad (2)$$

whereby $^{15}N_f$ is the ^{15}N content from ^{15}N–fertilized treatments, $^{15}N_r$ is the ^{15}N content of the reference material (determined from samples taken before application of the isotopically enriched N), $^{15}N_i$ is the initial ^{15}N application, N_t is the total N content of soil or plant biomass.

Statistical analyses

Statistical analyses were performed with JMP software (SAS Institute, 2007). All procedures were performed at $p<0.05$, unless otherwise indicated. Significant treatment effects were determined using the Students t-test.

Results

Maize yields and nitrogen uptake

At the 90% secondary N fertilizer application rate, increasing the biochar application rate did not significantly ($p>0.05$) change maize grain yield in any year (Table 2). Maize grain yields also did not change with biochar application of 12 t ha^{-1} ($p>0.05$) at lower or higher secondary N fertilizer application (Table 3). Similarly, biochar did not affect ($p>0.05$) tissue N concentrations, total N uptake or N uptake from applied fertilizer within any year (Tables 4 and 5). With the exception of 2007, maize yields increased with greater fertilizer N additions. In addition, aggregated across all years, N tissue concentrations and N uptake were significantly increased with 100% fertilizer application in comparison to 50% fertilizer addition (Table 5; N concentration with biochar only at $p<0.1$).

Table 1.2 Maize grain yield on a New York Alfisol amended with biochar in April 2007. Secondary fertilizer N application is maintained at 90% of recommended rate for all treatments. Different letters indicate significant differences between biochar application rates within single years (Students t-test; *p*<0.05; *n*=3). Letters are not shown when differences are not significant.

Biochar (t ha^{-1})	Year			
	2007	2008	2009	2010
0	4.74	9.26	8.50	8.69
3	4.11	7.80	8.51	8.60
12	4.19	8.14	7.93	8.62
30	4.02	7.66	6.59	7.81
1 yr^{-1}	4.05	7.48	8.56	9.08
p (biochar effect)	0.54	0.33	0.66	0.49

Table 1.3 Maize grain yield with varying N fertilization following biochar soil application in April 2007. Different letters indicate significant differences between treatment means within single years (Students t-test; *p*<0.05; *n*=3). Letters not shown when differences are not significant.

N application rate	Year								*p* (biochar effect)
	2007		2008		2009		2010		
(%)	0 t ha^{-1}	12 t ha^{-1}	0 t ha^{-1}	12 t ha^{-1}	0 t ha^{-1}	12 t ha^{-1}	0 t ha^{-1}	12 t ha^{-1}	
50	5.66	3.38	6.99	6.83b	6.50	6.64b	7.29b	7.41	0.3221
70	4.27	3.38	7.37	8.28ab	8.01	7.75ab	8.42ab	8.23	0.9948
90	4.74	4.20	9.26	8.14ab	8.50	7.89ab	8.69a	8.62	0.5364
100	4.50	4.66	10.41	11.38a	8.59	10.91a	8.94a	8.94	0.4064
p (N effect)	0.2307	0.1986	0.1667	0.0134	0.0984	0.0131	0.0126	0.1010	

Table 1.4 Tissue N concentration and total above-ground maize N uptake following biochar soil application in April 2007. Different letters indicate significant differences between treatment means within single years (Students t-test; $p<0.05$; $n=3$). Letters not shown when differences are not significant.

Year	Secondary N fertilizer (% of recommended fertilizer application)	Tissue N concentrations ($mg\ g^{-1}$)		Total N uptake (kg total N ha^{-1})	
		0 t ha^{-1}	12 t ha^{-1}	0 t ha^{-1}	12 t ha^{-1}
2007	50	6.63	6.41	55.7	46.6
	100	8.05	6.80	68.8	58.7
2008	50	7.21	7.55	78.3	80.4
	100	8.45	8.47	116.2	116.3
2009	50	7.55	7.84	72.9	69.5
	100	9.43	9.02	112.3	121.6
2010	50	8.62	8.01	97.50	87.82
	100	9.04	8.86	113.01	116.23
p (N effect)		0.0044	0.0438	0.0117	0.0048

Table 1.5 Above-ground maize biomass recovery of isotopically labeled N and N derived from fertilizer (year = 2009); microbial biomass and microbial biomass recovery of isotopically labeled N and N derived from fertilizer from soils taken in October 2009; nitrogen mineralization potential of soils taken in October 2009; DON adsorption constants for the Freundlich isotherms. Students t-test ($p < 0.05$, $n = 3$).

	Secondary N fertilizer (% of recommended fertilizer application)					
	50			100		
	0 t ha^{-1}	12 t ha^{-1}	*p* (biochar effect)	0 t ha^{-1}	12 t ha^{-1}	*p* (biochar effect)
Maize biomass $\delta^{15}N$ (‰)	1115.5	1344.2	0.434	1143.1	1126.6	0.919
Maize biomass N derived from fertilizer (kg total N ha^{-1})	19.1	22.3	0.459	54.9	60.4	0.474
Total microbial biomass N (mg kg^{-1}soil)	0.046	0.063	0.497	0.064	0.082	0.598
Microbial biomass $\delta^{15}N$ (‰)	84.1	133.1	0.670	85.5	204.4	0.125
Microbial biomass N derived from fertilizer (kg total N ha^{-1})	0.09	0.13	0.80	0.10	0.30	0.093
Maximum adsorption potential of DON (μg g^{-1})	10.6	10.2	0.9137	12.0	9.0	0.2996
Affinity constant	0.003	0.002	0.1487	-0.001	0.023	0.2647
Nitrogen mineralization (kg N ha^{-1} day^{-1})	1.30	1.09	0.3921	1.16	0.94	0.9577

Soil nitrogen

There were no consistent trends in measured soil mineral N contents with depth (Fig. 1). In contrast, the $\delta^{15}N$ values and the N derived from fertilizer of total N were significantly ($p<0.05$) greater in the topsoil (0-0.2 m) with biochar application where 100% of recommended fertilizer was applied (Fig. 2; no differences with 50% fertilization). In the subsoil, however, ^{15}N enrichment and N recovery from applied fertilizer was greater without biochar additions (only significant at 0.3-0.4 m; 11.56±3.79 ‰ in control and 2.65±3.79 ‰ with biochar).

Nitrogen in microbial biomass was not significantly different at any fertilizer application rate ($p>0.05$). However, three times more fertilizer N was recovered with biochar in the microbial biomass than without biochar ($p=0.093$). Nitrogen mineralization potential and DON adsorption did not change irrespective of biochar additions or fertilizer application rates (Table 5).

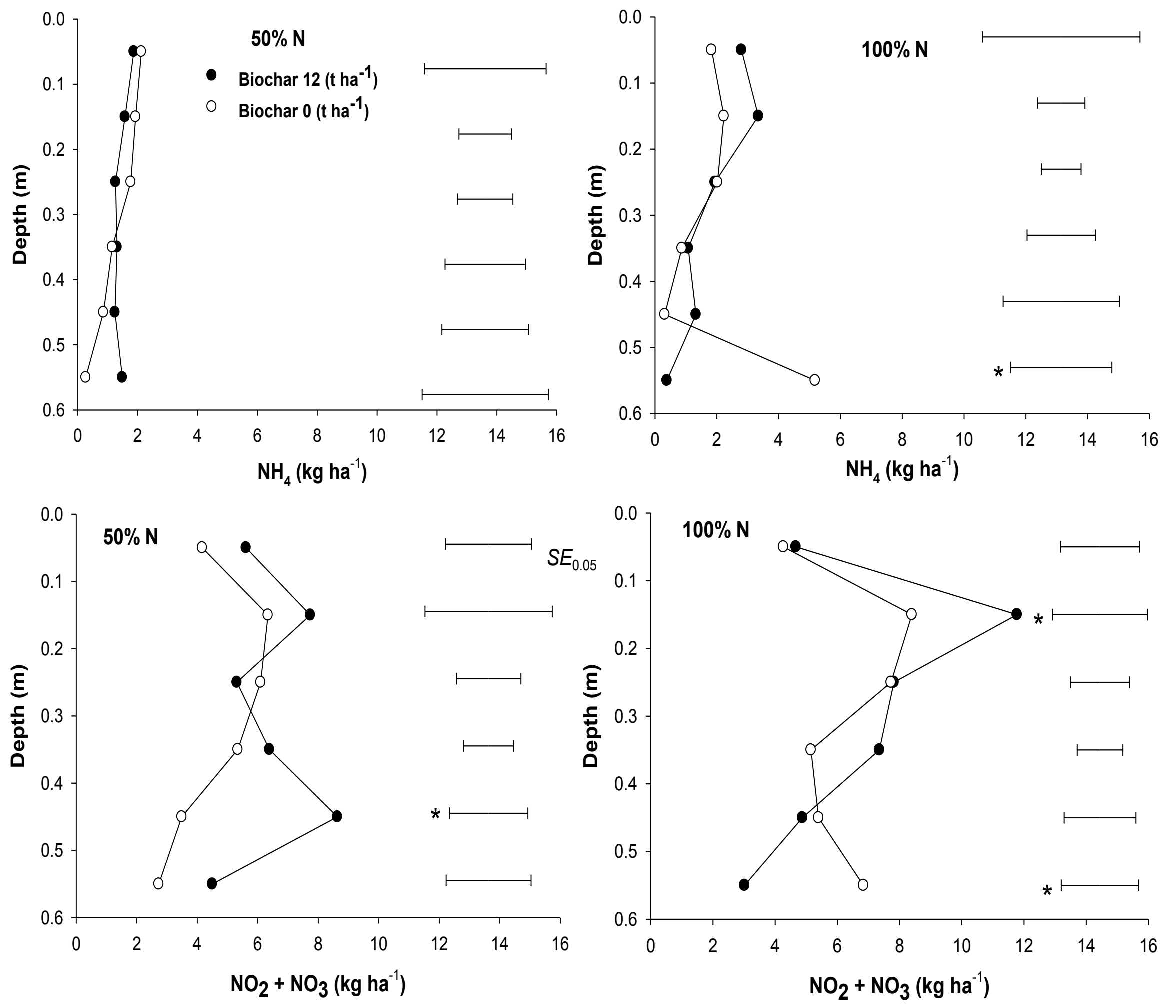

Fig. 1.1 Soil profile mineral N at 50 and 100% secondary fertilizer N application rate and 0 and 12 t ha^{-1} biochar application rates after harvest in October 2009. * indicates significant differences (p<0.05; n=3) within an individual depth and between treatments.

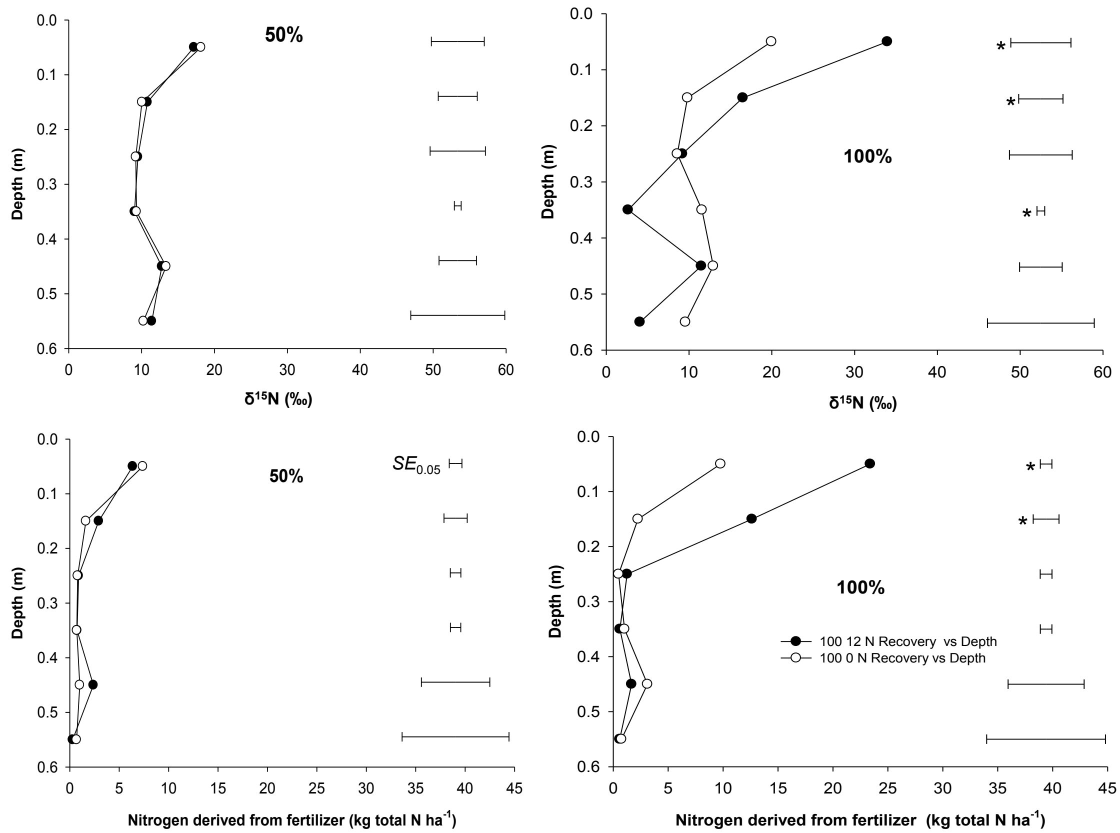

Fig. 1.2 Soil profile ^{15}N concentration and recovery of N derived from fertilizer at 50 and 100% secondary fertilizer N application rates and 0 and 12 t ha^{-1} biochar application rates after harvest in October 2009. * indicates significant differences (p<0.05; n=3) within an individual depth and between treatments.

Nitrogen leaching

There were no significant differences in any leaching metric between the control and biochar treatments at 50% of recommended N fertilization (p>0.05) (Table 6). However, at 100% of recommended fertilization, total and mineral N flux, flow-weighted average NH_4 and NO_3 concentrations and their fluxes, N flux and flow-weighted average N derived from fertilizer, and total water drainage were greater in the control than with biochar. Flow and concentrations of organic N were not significant different between any treatment.

Table 1.6 Nitrogen forms in leachate collected from free-draining lysimeters and N leaching as a result of biochar additions to soil with high and low secondary N fertilizer application rates during 2009. (Students t-test; $p<0.05$; $n=3$). 521.5 mm total measured rainfall during the sampling period.

	Secondary N fertilizer application rate (%)					
	50			100		
	Biochar application rate (t ha^{-1})					
	0	12	*p* (biochar effect)	0	12	*p* (biochar effect)
Total N flux (kg ha^{-1})	52.40	67.46	0.198	150.68	27.48	0.039
Flow-weighted average total N (mg L^{-1})	4.80	9.85	0.322	8.42	5.23	0.321
Total mineral N flux (kg ha^{-1})	32.42	63.69	0.267	121.59	17.24	0.007
NH_4 flux (kg ha^{-1})	0.67	1.05	0.396	11.42	0.95	0.024
Flow-weighted average NH_4 (mg L^{-1})	0.07	0.14	0.253	0.90	0.16	0.047
NO_3 and NO_2 flux (kg ha^{-1})	31.75	62.64	0.266	110.17	16.29	0.006
Flow-weighted average NO_3 and NO_2 (mg L^{-1})	3.70	8.09	0.208	8.67	2.94	0.043
Organic N flux (kg ha^{-1})	8.73	1.57	0.286	23.64	10.24	0.545
Flow-weighted average organic N (mg L^{-1})	1.03	1.62	0.438	3.34	2.19	0.407
$\delta^{15}N$ (‰) of total N	391.99	53.85	0.231	702.03	242.20	0.068

$\delta^{15}N$ (‰) of flow weighted average	14.93	8.76	0.547	33.53	12.34	0.258
Total N flux derived from fertilizer (kg ha^{-1})	0.007	0.05	0.407	0.42	0.05	0.024
Flow-weighted average N derived from fertilizer (mg L^{-1})	0.0003	0.002	0.405	0.01	0.003	0.035
Total water flow (mm)	898	676	0.513	1282	611	0.026

The largest single rainfall event for the 2009 season occurred at the end of June (Fig. 3). This event corresponded to a major leaching loss of nitrate but was not reflected in $\delta^{15}N$ values or the leaching losses of N derived from fertilizer. Discharge and N losses were only different for few individual sampling dates (p>0.05).

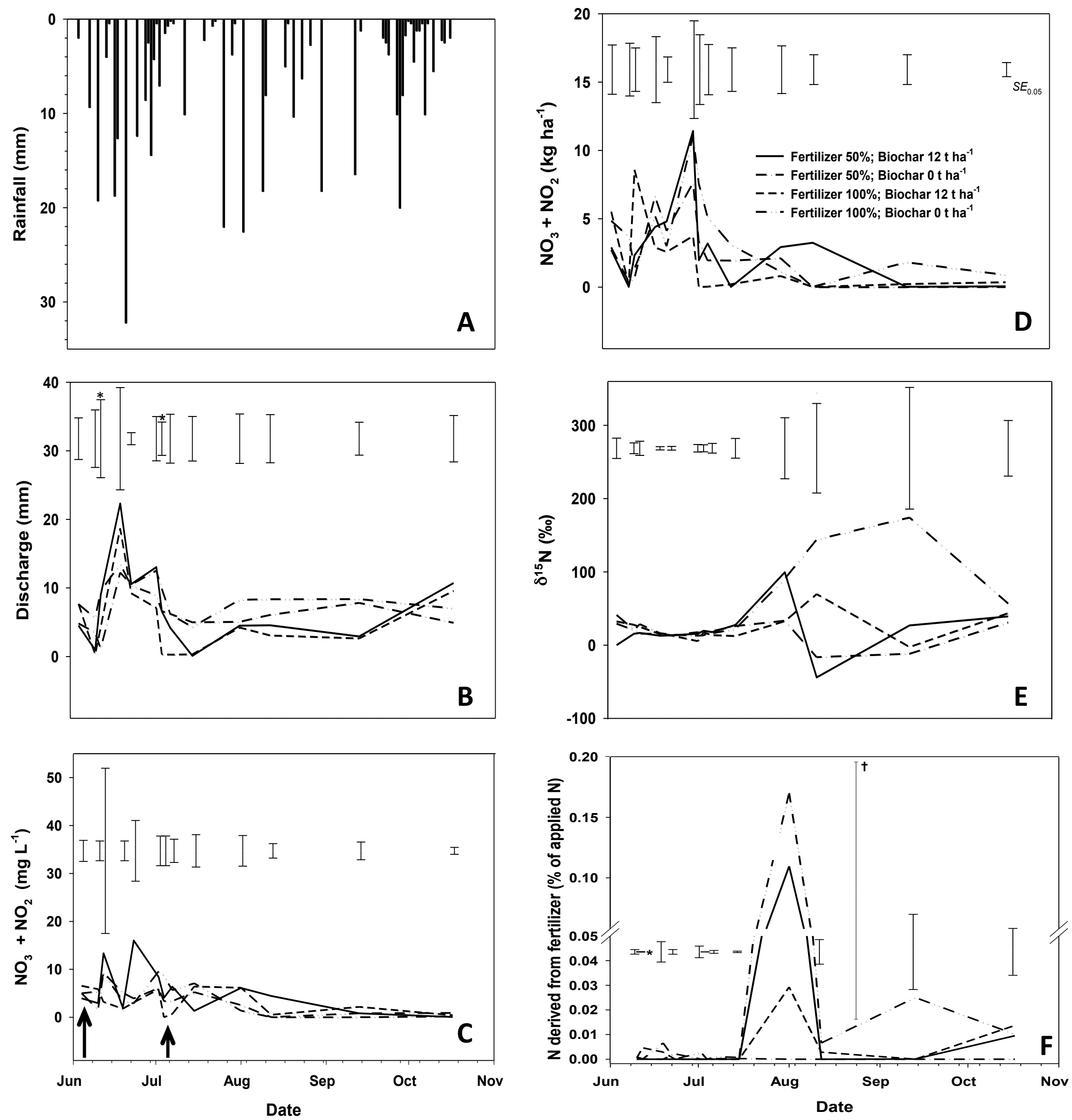

Fig. 1.3 Leaching data as function of time for the 2009 growing season. Data includes season rainfall (A), discharge (B), NO_3 and NO_2 concentrations (C), NO_3 and NO_2 fluxes (D), $\delta^{15}N$ (E), and N derived from fertilizer (F). * indicates significant differences (p<0.05; n=3). Note scale change in the Y-axis in graph (F). Error bar marked with † in graph (F) is the error bar for the August 1 data points. Arrows in graph (C) indicate initial and secondary fertilization events, respectively.

Fertilizer nitrogen recovery

The proportion of total fertilizer N recovery was not significantly different in fields that received biochar and the unamended control at 50% of recommended fertilization, but was 37% greater (p=0.1) at 100% fertilization (Fig. 4). At 100% fertilization, the proportion of total recovered fertilizer microbial biomass N was significantly greater (p = 0.053) with than without biochar additions (not significantly different at 50% fertilization). Conversely, the proportion of fertilizer N leaching losses were greater in the control than with biochar.

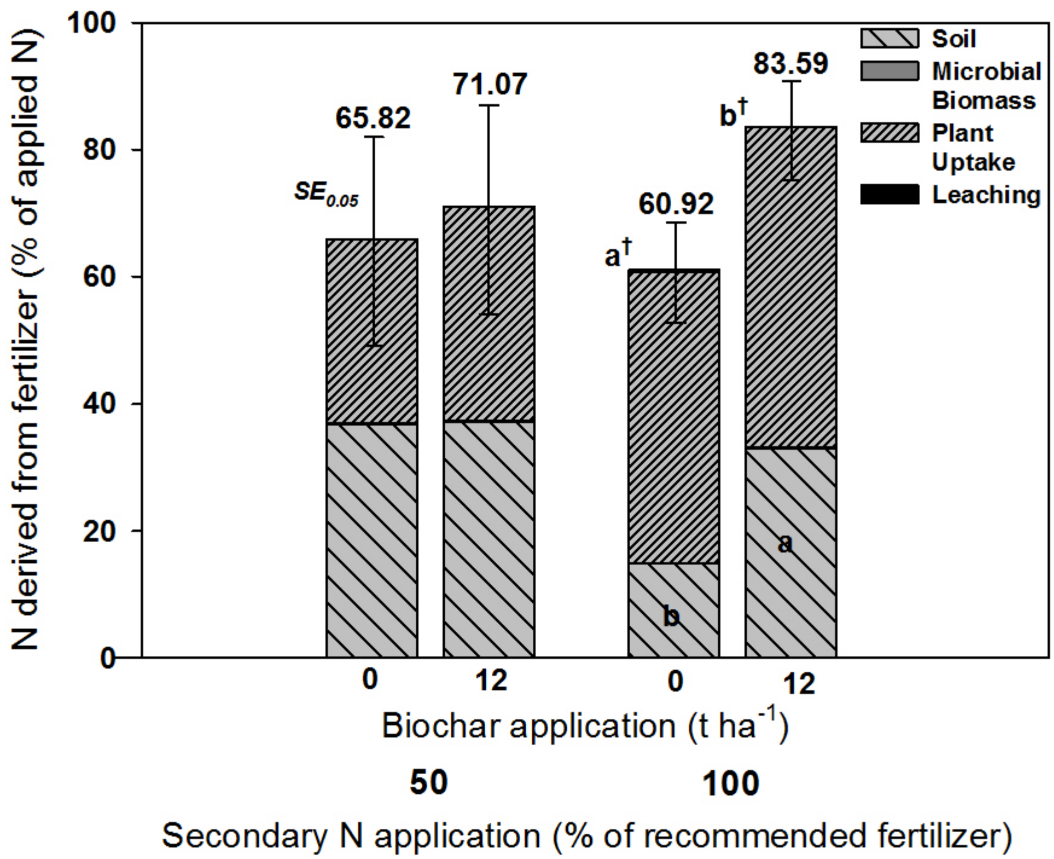

Fig. 1.4 Proportion of N recovery in soil, microbial biomass, plant, and leachate derived from fertilizer in control soil and biochar-amended soil with high and low secondary N fertilizer application rates in 2009 (means and standard errors). Values above bars show total N recovery. Different letters indicate significant differences between biochar application rates within secondary N fertilizer application rates and N pools (Students t-test; p=0.05; n=3). Letters not shown when differences are not significant. †N recovered in leachate.

Discussion

Crop yield, nitrogen uptake and leaching

In contrast to our study, yield increases in maize following biochar applications have been widely reported from field trials with biochar manufactured under various production conditions and from diverse feedstocks (Rondon et al. 2006; Yamato et al. 2006; Kimetu et al. 2008; Major et al. 2010; Van Zwieten et al. 2010a). Most of this work has been done in tropical cropping systems where biochar may alleviate low pH, Al toxicity, and improve CEC (Lehmann et al. 2003; Van Zwieten et al. 2010a). However, the soils studied here have sufficiently high native fertility, adequate CEC, neutral pH, and yields with full fertilization are within the range of current average yields for North America (Martin et al. 2005). The crop received appropriate amounts of pesticides and therefore any benefits of decreasing severity of plant diseases as observed after biochar additions by Elad et al. (2010) are not expected.

While the biochar applications did not alter crop yield, biochar significantly reduced cumulative N losses due to leaching at the high N fertilization rate, however at low total N leaching losses. The fact that both total leached N as well as N leaching from applied ^{15}N showed proportionally similar reductions after biochar additions lends additional credence to the interpretation that biochar significantly reduced leaching of applied fertilizer, but evidence from individual sampling dates is weak. In addition the $\delta^{15}N$ value of the total N recovered in the leachate was 290 % greater without biochar than with at the high fertilization rate ($p = 0.0675$). Other leaching studies with biochar applications have also reported net reductions of leaching of N and other nutrients in lysimeter studies without plants (Lehmann et al. 2003; Novak et al. 2009; Laird et al. 2010b) and in the field with a maize crop (Major et al. 2011). It is interesting that there were no measured differences in leaching losses with 50% fertilization in our study.

Fertilizer N was retained to a greater extent (p<0.1) in soil, though, at the low N application rate (36-37% of applied N without and with biochar, respectively) than with the high N application rate (15-33%).

In N-limited soils from Japan and Colombia, biochar was demonstrated to increase N availability and plant N uptake (Yamato et al. 2006; Major et al. 2010), however, in N-limited soils in Kenya, applications of biochar had beneficial effects on plant growth without increasing plant N uptake (Kimetu et al. 2008). In an Oxisol from Brazil, N uptake even decreased likely due to N immobilization with biochar (Lehmann et al. 2003), similar to the decrease observed with a non-fixing bean isoline grown on an Oxisol from Colombia (Rondon et al. 2007). In the present experiment biochar did not affect aboveground maize N uptake. Therefore, the reduction in leaching with biochar can be unambiguously interpreted as being due to a greater retention of N in soil, and not a result of greater plant N uptake. To our knowledge this is the first time retention of N by biochar in soil is shown for a field experiment including plants that can not also be explained by increased N uptake.

Mechanism of nitrogen retention

The classic mechanism of nutrient retention on biochar is the greater sorptive capacity of biochar added to the soil through increases in CEC (Liang et al. 2006). The observed reductions in NH_4^+ leaching may be explained by adsorption, similar to the observations made by Lehmann et al. (2003) with applied ammonium sulfate in a short-term lysimeter study. However, NO_3^- was the dominant N species responsible for N leaching losses in our study, being about one order of magnitude greater than NH_4^+. While fresh biochar may have some anion exchange capacity (AEC), at the pH of this soil the AEC would be negligible (Cheng et al. 2008). Therefore electrostatic adsorption of NO_3^- by biochar is not a likely mechanism to explain greater N retention in the soil with added biochar. This is also confirmed by the lack of a difference in exchangeable NO_3^- in the topsoil with biochar additions.

Nonetheless, N leaching mainly in the form of NO_3^- was reduced by biochar additions in the present experiment without an increase in exchangeable NO_3^- and more total N from fertilizer was found in the soil (35% of the applied N with biochar, 15% without biochar in the total soil at p=0.0498). Therefore, the remaining N must be held in the organic pool (35% of the applied N with biochar, 15% without biochar in total soil), with 0.08-0.09% of applied N being recovered in the microbial biomass pool with additions of biochar and 0.02-0.05% recovered without biochar. Increases in microbial biomass after biochar additions have also been documented in other studies (Steiner et al. 2004; Kolb et al. 2009; Kuzyakov et al. 2009) and a retention of fertilizer N by microbial cycling has been suggested by Steiner et al. (2008). Our experiment may indicate that the mechanism for N retention and leaching reduction is indeed the incorporation into microbial biomass and cycling into the organic pool. Whether this can be generalized to other locations would need to be verified.

In addition to microbial processes, biochar is known to have a high sorption affinity for organic C compounds, both of percolating dissolved organic C (Pietikäinen et al. 2000; Chun et al. 2004) and organic pollutants (Smernik 2009). Consequently, Jin (2010) found significantly greater adsorption of dissolved organic C (DOC) to soil amended with biochar. However, the present study did not detect any increased DON adsorption in the presence of biochar. The reason why DOC adsorption assessed by Jin (2010) increased with biochar and DON adsorption did not increase in this study at the same site, may be explained by the present assessment being done two years later when adsorption sites may potentially have already been occupied. It is also conceivable that surface oxidation of biochars over time leads to decreased adsorption of non-polar organic compounds as shown by Cheng and Lehmann (2009). In addition, the high ash content of the applied biochar may result in low hydrophobicity and adsorption of organic molecules. Regardless of the reason, increased DON adsorption is therefore not the reason for N retention and accumulation of organic N, and the process by which microbial N is retained in non-living soil organic N remains elusive.

Gaseous nitrogen losses

Between 17% and 39% of the applied fertilizer was not accounted for by leaching, plant uptake and soil retention with or without biochar additions, respectively. Erosion is unlikely to have played a major role, as the site is tile-drained and is not sloping. Some of the unaccounted losses may have occurred in gaseous form, and would appear to be lower after biochar additions. Taghizadeh-Toosi et al. (2011) found lower nitrous oxide emissions from pasture soils that received biochar, which may be indicative of lower gaseous N losses by denitrification. However, not all available studies showed a reduction in nitrous oxide emissions (Scheer et al. 2011) and no published study investigated total N losses by denitrification including N_2. The findings of greater N recovery provides direct evidence for improved N use efficiency through retention of N in microbial biomass and organic N in soil. Such greater N retention in soil microbial biomass may also explain the findings of several other studies who reported greater N use efficiency in a range of soils (Chan et al. 2007; Steiner et al. 2008; Van Zwieten et al. 2010b).

Applications of biochar derived from maize stover reduced the leakage of N into the ground water while not affecting yields or N uptake over the first 4 years after application. In this part of the North Eastern United States, groundwater pollution with N is a major environmental burden from agriculture (Howarth et al. 1996; Matson et al. 1997; Carpenter et al. 1998). Based on the results from this study, applying biochar to the soil will reduce N leaching losses while not adversely affecting agricultural productivity.

Conclusion

Based on this study, applications of biochar up to 30 t ha^{-1} do not adversely affect agricultural productivity in temperate soil that has little soil quality constraints. Expectations of biochar to increase crop yields in such fertile temperate soils may not be expected. It is the norm rather than the exception for maize yields in the region to consistently achieve genotypic and phenotypic yield potentials. The greater N recovery in the topsoil after one season may suggest that N retention can be increased with one-time biochar additions even to fertile soils, but did not result in greater N uptake here. This result would need to be verified across a range of biochars to determine if the microbial N accumulation is a product of this particular feedstock or production procedure.

This study provides some indication that the accumulation of applied fertilizer N in the topsoil may be linked to N cycling through the microbial biomass. Less clear is the micro-location of the microbial biomass N, the form of the retained N and what processes and properties of biochar were responsible for an enhanced cycling of N through the microbial biomass. Future research should investigate N cycling with different biochars and soil types, and how N accrual in soil, availability and leaching changes over decadal time scales and what the mechanism is that leads to incorporation of applied N in microbial biomass following biochar additions.

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APPENDIX

Table 1.7 Biochar properties.

	Units	
pH (water)		10.02
Potential CEC	(mmolc kg^{-1})	343
Total C	(mg g^{-1})	290
Total N	(mg g^{-1})	3.05
C/N		96
Total O	(%)	8.1
Total H	(%)	1.5
O/C[a]		0.15
H/C[a]		0.43
Total P	(mg g^{-1})	0.41
Total Ca	(mg g^{-1})	45.6
Total K	(mg g^{-1})	275.2
Total Mg	(mg g^{-1})	7.5
Total Na	(mg g^{-1})	25.1
Extractable Ca	(mmolc kg^{-1})	45.6
Extractable K	(mmolc kg^{-1})	275.2
Extractable Mg	(mmolc kg^{-1})	7.5
Extractable Na	(mmolc kg^{-1})	25.1
Ash (ASTM)	(%)	64.19
Fixed carbon (ASTM)	(%)	10.12
Volatile matter (ASTM)	(%)	71.74
Surface area (CO_2)	m^2 kg^{-1}	178

[a]molar ratios

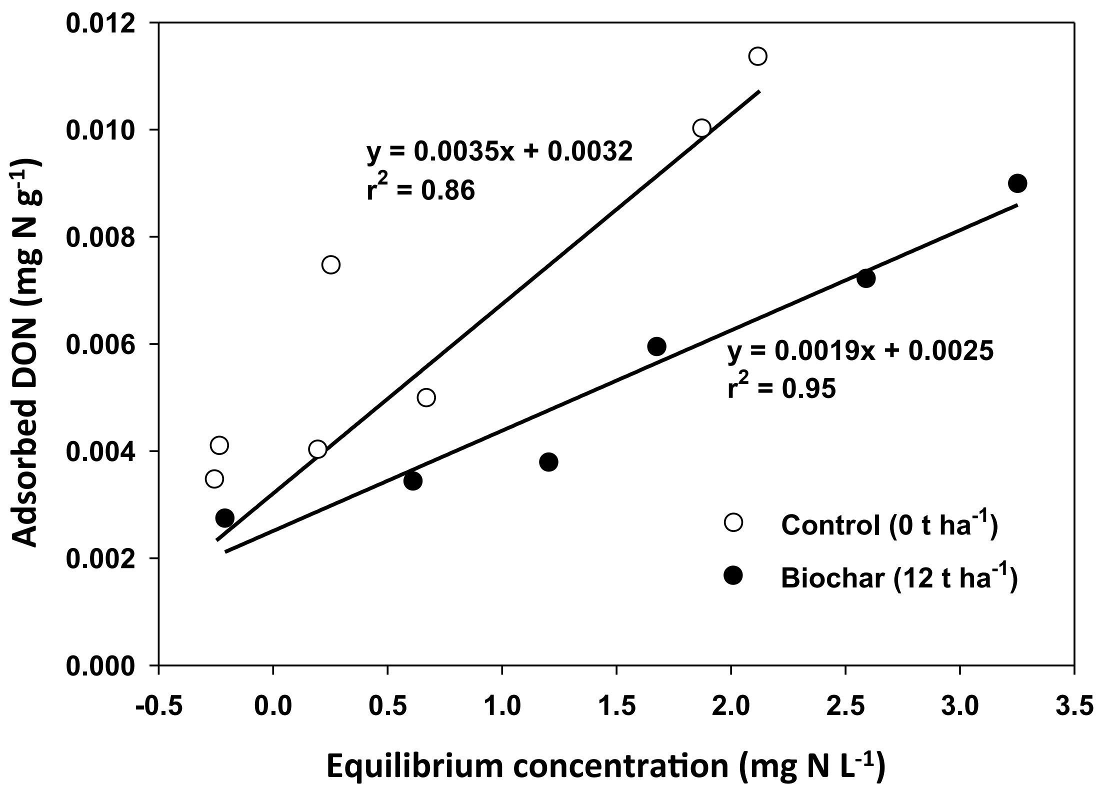

Fig 1.5 Adsorption isotherms of DON for a control soil and a soil ammended with biochar from upstate New York.

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CHAPTER 2

RESIDUAL EFFECTS OF ORGANIC SOIL INPUTS OF CONTRASTING QUALITY

Abstract

Soil fertility is the main biophysical constraint to crop productivity in Sub-Saharan Africa. Lack of affordable mineral fertilizers and intensive farming has resulted in wide-spread loss of soil nutrients and a corresponding loss of soil organic matter. Soils depleted of organic matter often respond poorly to mineral fertilizers and are less resilient to global climate change. The residual effects of organic inputs of contrasting quality on maize productivity were investigated as a function of soil degradation in the highlands of western Kenya. Tithonia (*Tithonia diversifolia* (Hemsl.) A. Gray) green manure, cypress sawdust, and biochar made from eucalyptus wood were applied at a rate of 6 t C ha^{-1} for three cropping seasons, both with and without mineral fertilizer additions (120 kg N ha^{-1}, 100 kg K ha^{-1}, 100 kg P ha^{-1}). Maize grain yield was monitored for four years beyond the initial organic matter additions. The greatest yield responses for all amendments were found on the most degraded soil. During those years when amendments were added, tithonia applications resulted in the greatest yield increases, between 153 and 183% more than the unamended control in comparison to 136% with biochar and 107% with sawdust additions. However, four years after tithonia applications to highly degraded soils stopped, yields rapidly declined to only 110% of the unamended control, whereas yields after biochar additions remained constant at 0.3-1.8 t yr^{-1} or 9-265% greater than yields without

organic amendments. Four years after organic matter additions ended, maize yields were not significantly different irrespective of additions of the quality of organic amendments. Even four years after organic matter additions, yields in response to fertilizer additions to highly degraded soils were 113% greater when applied together with the organic inputs than alone. Whether as a result of immediate or residual effects, no significant differences were found with or without fertilizer or organic matter additions in the farms recently converted from forest. The data indicate that yield responds in the short-term to input quality and specifically the amount of applied N; while the residual effects of organic matter additions on yield dynamics may relate more to input C quality and increasing soil C.

Introduction

The global hotspots for population growth, poverty, food insecurity, and ecological fragility converge in Sub-Saharan Africa (SSA) (Myers et al., 2000; Sanchez and Swaminathan, 2005). An estimated 60% of rural communities in these countries are chronically affected by declines in household food production and suffer from chronic caloric and nutritional deficiencies (UNDP, 2001). Many of these countries were bypassed by the yield gains of the Green Revolution technologies primarily as a result of biophysical limitations rather than distributional inequalities (Sanchez, 2002). The lack of affordable and available agronomic resources has led to the exploitation of natural capital to maintain food production. The farmers in these regions "cultivate marginal soils with marginal inputs, produce marginal yields, and perpetuate marginal living and poverty" (Lal, 2004). A substantial change in crop production is needed to reverse the trends in yield decline, increasing poverty, and environmental degradation.

Sub-Saharan Africa is the only region of the world where agricultural productivity has remained stagnant over the last few decades (Ehui and Pender, 2005). This has been largely due to cost barriers of synthetic fertilizers which are several times more expensive in SSA than in developed countries (Vanlauwe et al., 2001). Lack of available fertilizers has led agricultural production to be marginally maintained at equilibrium with consumption through extensification rather than intensification (Millennium Ecosystem Assessment, 2005; Wass, 1995; Wilson, 1992). Agricultural extensification has largely occurred through the conversion of natural lands marginally suited for agriculture. In equatorial SSA the most productive lands are located under the humid forests of the highlands which harbor some of the greatest concentrations of biodiversity on the planet (Myers et al., 2000; Wilson, 1992). Soil fertility management programs should be established which increase agricultural productivity and environmental sustainability using resources and technologies currently available to local farmers and land managers. Integrated soil fertility management programs (IFSM) have been recommended to sustainably intensify agricultural productivity in SSA through a combination of available organic resources and synthetic fertilizers (Vanlauwe et al., 2010), but information about integrating inorganic and various organic amendments is complex and sparse.

In addition, agronomic productivity is tied to both nutrient and C content in the soil (Chivenge et al., 2010; Kimetu et al., 2008, Ngoze et al., 2008; Six et al., 2002). In tropical soils degraded of C, nutrients supplied by synthetic fertilizers alone often have low nutrient use efficiencies (Baligar and Bennet, 1986). In these soils the addition of organic residues in conjunction with synthetic nutrient sources results in greater agricultural yields than the application of synthetic fertilizers alone (Chivenge et al., 2009; Gentile et al., 2011; Kimetu et al., 2008). However, in the short term, the magnitude and direction (positive or negative) of yield response is dependant on residue quality (Gentile et al., 2011; Palm et al., 2001). In the long-term, residue quality also affects soil C sequestration and maintenance of soil fertility (Chivenge et al., 2009; Kimetu et al., 2008).

The incorporation of low-quality organic residues into the soil can result in yield depressions in the short-term due to N immobilization, while in the long-term yields may increase once the C has been microbially stabilized (Chivenge et al., 2010). Possible mechanisms for the long-term yield improvements may include greater plant nutrition through improved cation retention, improvements in soil water retention, or beneficial alterations in the soil micro and macrobiota (Vanlauwe et al., 2001). High-quality organic residues have been shown to improve agricultural productivity in the short-term which is mainly attributed to higher amounts of nutrient additions, primarily N (Gachengo et al., 1999, Jama et al., 2000). However, these residues are decomposed very quickly, and most of the N is released by mineralization within a few weeks (Palm and Sanchez, 1991; Constantinides and Fownes, 1994).

In addition to the complexity of integrating inorganic and organic amendments, different soil fertility levels dictate the success of a particular strategy. Traditional land-clearing followed by intensive agricultural practices is initially successful even without inputs due to inherent soil fertility built up over centuries under native vegetation (Murtt et al., 2002). This soil fertility and the corresponding high crop yields are transitory, and soil fertility decreases rapidly during the initial years of cultivation after clearing from natural vegetation (Juo, et al., 1995; Lemenih et al., 2005; Kimetu et al., 2008; Ngoze et al., 2008). At what soil degradational state organic or inorganic additions are needed to maintain soil fertility is not well known.

When addressing soil fertility restoration for the long-term, organic matter additions should not necessarily be optimized for the greatest total nutrient additions, but rather a build up of soil organic matter and the associated soil biological, chemical, and physical changes (Lal, 2006). While additions of low-quality organic residues can result in N immobilization in the short-term (Palm et al., 1997) as discussed above, in the long-term the addition of more recalcitrant forms of organic matter can lead to the build up of soil organic matter. Increasing the stocks of soil organic matter may, under many soil conditions, be the only way to sustainably restore soil fertility in the tropics (Lal, 2006). Kipkiyai et al. (1999) demonstrated maize yields increased by 234 kg ha^{-1} for every Mg C ha^{-1} conserved through soil management practices and maize grain yield was found to increase linearly with increases in SOC (Lal, 1981).

Recent studies have demonstrated biochar as a potential soil fertility amendment with particular efficacy for soils of the humid tropics (Glaser et al., 2002; Steiner et al., 2007; Major et al., 2010). Biochar is a low quality organic input with a C:N generally greater than 30 (Krull et al., 2009). However, the C in biochar is in a form that is regarded as unavailable to short-term microbial mineralization (Lehmann, 2007) and, depending on production conditions, does not result in N immobilization (DeLuca et al., 2009). As other forms of soil organic matter, biochar has chemically active surfaces and when applied to the soil has resulted in physicochemical (Cheng et al., 2008; Liang et al., 2006), microbial (Thies and Rillig, 2009; Warnock et al., 2007) and physical (Glaser et al., 2002) changes that can be beneficial to agricultural productivity.

Relative to other forms of organic residues, biochar is highly recalcitrant to microbial degradation (Lehmann et al., 2009). From a soil fertility perspective, a single application of biochar to the soil can potentially enhance agricultural productivity for the long-term. However, there are no direct studies quantifying the long-term effects of biochar application on soil fertility and the interaction with synthetic fertilizer application relative to other forms of soil applied organic residues.

The objectives of this study were to quantify maize yield dynamics as a result of residual effects of the application of organic materials of contrasting quality along a gradient of soil fertility and to assess the interactive effects of fertilizer additions in conjunction with the organic residue additions along this same gradient.

Methods

Site description

The study site was located in the Nandi and Vihiga counties of western Kenya (34°94'23" E Lat.; 00°13'44" N Long.) at altitudes between 1,542 and 1,837 m above sea level. The rainfall pattern is bimodal with the main rainy season (long-rains) falling between March and August followed by a shorter rainy season (short-rains) falling between August and December. Mean annual precipitation for the area is around 2000 mm. The measured rainfall from two collection centers in the project area are presented in Table 1. Mean annual temperature is 19°C. The native vegetation is tropical highland rainforest and represents the eastern most extension of the Guineo-Congolian rainforest (Wass, 1995).

Table 2.1. Rainfall (mm) data from two locations adjacent to the experimental farms. Data is for the long-rain growing season and the yearly total.

	Forest Station		Tea Estate	
Year	Long-Rain	Year Total	Long-Rain	Year Total
2005	1276	1712	1738	2486
2006	1163	2141	1163	1712
2007	1163	1712	1397	2150
2008	1142	1686	1493	1936
2009	905	1565	982	1684
2010	1257	2117	1614	2146

At this location a chronosequence of land conversion and soil fertility decline was established (Kinyangi, 2008). Chronosequences can be a practical method to assess soil fertility degradation and restoration dynamics in a relatively short time frame (Stevens and Walker, 1970; Hugget, 1998; Kimetu et al., 2008). As time progresses from conversion of the native vegetation, soil C, soil nutrients, and crop productivity exponentially decline (Ngoze et al., 2008).

The selected fields are located on farms converted in the year 1900 to land cleared as recently as 2002. A subset of 27 farms from this chronosequence was chosen that encompass approximately 60 linear km of distance, with the most recent conversions and up to land converted in the 1950's being located within 10 km^2 of each other (Kimetu et al., 2008; Ngoze et al., 2008). The chronosequence is located on humic Acrisols derived from granite basalt and humic Nitisols derived from biotite gneisse (Sombroek et al., 1982). The subset of farms on heavy-textured soil was chosen for this study and is texturally homogenous between experimental sites and the remaining forest (Kimetu et al., 2008; Ngoze et al., 2008). Time since conversion was determined based on Landsat imagery, private interviews, and official records (Kinyangi, 2008). Historically, the farms had received little inorganic fertilizer and have been primarily cropped to maize and other cereals since clearing (Croweley and Carter, 2000).

Beginning in 2005, organic inputs of contrasting quality were applied to sub-plots on the farms converted circa 1900, 1925, 1950, 1970, 1985, and 2000 (Kimetu et al., 2008). Leaves of *Tithonia diversifolia* (Hemsl.) A. Gray (tithonia), cattle manure, biochar, and sawdust were applied at the rate of 6 t C ha^{-1} for three consecutive seasons (2005 long-rains, 2005 short-rains, and 2006 long rains). Biochar was produced from *Eucalyptus saligna* wood using the traditional earthen kiln method at temperatures of approximately 400 – 500°C. Sawdust was collected from a local saw-mill and was composed of primarily cypress wood.

The organic inputs were applied in duplicate to each farm. One set of treatments received complete fertilizer (N, P, K) (plot size 4 m by 4.5 m) in all years, while the other set received only P and K at 100 kg ha^{-1} each (plot size 2 m by 2.25 m) for the planting years 2005 – 2008. From 2009 these plots received no fertilizer of any kind. A set of controls was also established (plot size 2 m by 2.25 m); all controls received none of the aforementioned organic inputs. There were three controls in total: full fertilization, no N (2005-2008) with no fertilizer applied since 2009, and a plot chosen at random from the farmer-managed land (FP).

Table 2.2 Experimental design. All treatment combinations were established in three replicate farms (*n*=3).

Organic amendment (t ha^{-1})	Fertilization (N-P-K kg ha$^{-1)}$			
	0-0-0	Plot size (m)	120-100-100	Plot size (m)
Tithonia	X	2 x 2.25	X	4 x 4.5
Biochar	X	2 x 2.25	X	4 x 4.5
Sawdust	X	2 x 2.25	X	4 x 4.5
Control	X	2 x 2.25	X	2 x 2.25
Farmer Practice	X	2 x 2.25	-	-

The fertilizer was a mixture of urea, triple super phosphate, and muriate of potash applied at 120 kg N ha^{-1}, 100 kg P ha^{-1}, and 100 kg K ha^{-1}. A completely randomized block design was used with three replicated farms per conversion age. All of the P and K was broadcast applied at planting, while one third of the N was broadcast applied at planting and two thirds broadcast applied approximately six weeks after planting. Maize (Hybrid 614, Kenya Seed Company, P.O. Box 553 – 30200 Kitale, Kenya) was planted with distances of 0.75 m between rows and 0.25 m within rows. Weeding was done by hand hoes six weeks after planting and again before silking.

Sampling and analysis

Maize grain and stover yields were determined in all plots at the end of the growing season when the majority of plants had reached physiological maturity. Yields were measured on subplots of 3 m by 1.5 m and 1 m by 2.25 m (for plots with and without N and with and without organic amendments, respectively) to avoid edge effects. Total wet biomass and total wet cob weight was measured in the field with a resolution of 0.1 g. A subsample of stover and cobs was taken and dried at 60°C until a stable weight was obtained. These samples were used to correct for oven-dry total biomass and grain weights.

During grain-filling, maize tissue samples were taken for abscisic acid (ABA) analysis, a plant water-stress hormone. Abscisic acid (ABA) analysis is commonly used as a direct measurement of plant-water stress. Abscisic acid measurements are only valid for comparison within one genotype (Quarrie and Jones, 1976; Quarrie et a., 1997) as applied here. Vials were filled with cold 80% ethanol and transported to the field sites in a cooler. Five randomly selected tissue samples were taken from one plant, five randomly selected plants were chosen per plot for a total of 25 samples per plot. Tissue samples were taken using a paper hole-punch. The hole-punch was cleaned with ethanol between plants. The tissue samples were then transported in coolers and placed immediately into refrigeration. The vials were then evaporated in ovens at 105°C for transportation to Cornell University. The ABA was then dissolved in 15 mL of 80% ethanol and ABA concentrations were determined following the enzyme-linked immunosorbent assay (Daie and Wyse, 1981).

Statistical analyses

Statistical analyses were calculated using analysis of variance, linear or non-linear regressions (JMP, SAS Institute, Cary, NC). All procedures were performed at $P<0.05$, unless otherwise indicated.

Results

Soil degradation gradient

As land conversion age increased, maize grain yields decreased following an exponential decay curve (Fig. 1). Yields from 2009 appear to follow a linear trend and were 36% of the yields measured in 2010. The greatest yields were measured in the youngest conversion sites, which were converted in 2002 with 4 and 6 t ha^{-1} for the 2009 and 2010 growing seasons, respectively. Lowest yields were measured on oldest conversion sites, converted in 1900. These yields were 1 t ha^{-1} for both years. On average over all conversion ages, yields were 25% higher ($P<0.05$) with fertilizer than without. However, this difference was not seen in the young conversion and fertilizer did not increase yields ($P>0.05$) and only appeared ten years after conversion with an average increase of 1.9 t ha^{-1} (difference in Yo of the regressions in Fig. 1). Yields in the old conversions increased by 61% with fertilization (P<0.05). Maize yields significantly increased with any organic matter addition compared to both the researcher-managed control as well as the plots that were managed according to farmer practice (Fig. 2). However, maize yields were not significantly different by varying the quality of organic input at any conversion age, in both 2009 and 2010.

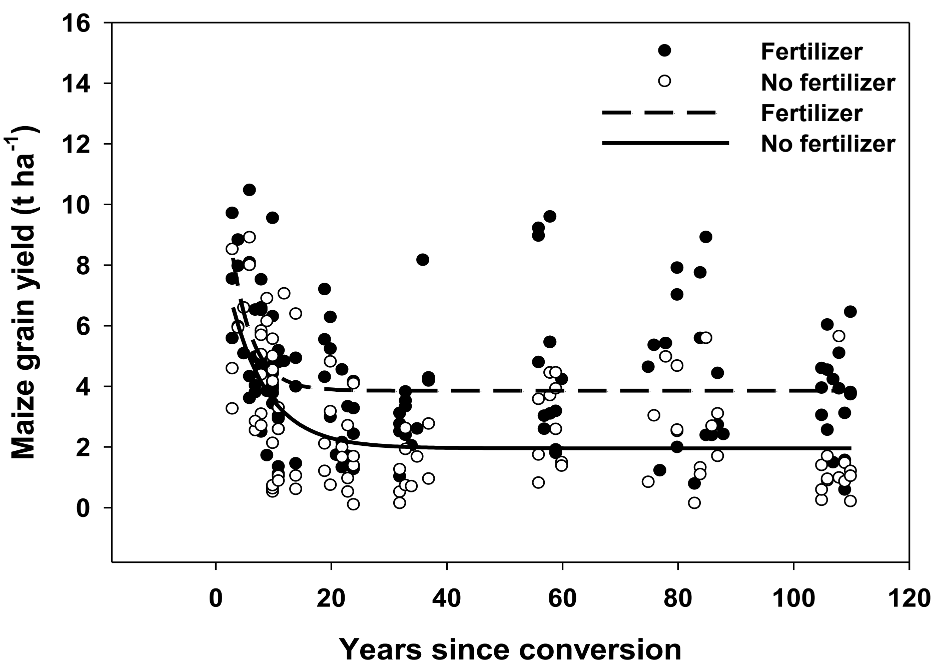

Figure 2.1. Grain yield response to fertilizer additions as a function of land conversion age and soil fertility without organic amendments. Fertilizer $y = 3.86 + 10.25^{-0.28x}$; r^2 = 0.17. No fertilizer $y = 1.96 + 7.38^{-0.15x}$; r^2 = 0.32. Year = 2005 - 2010.

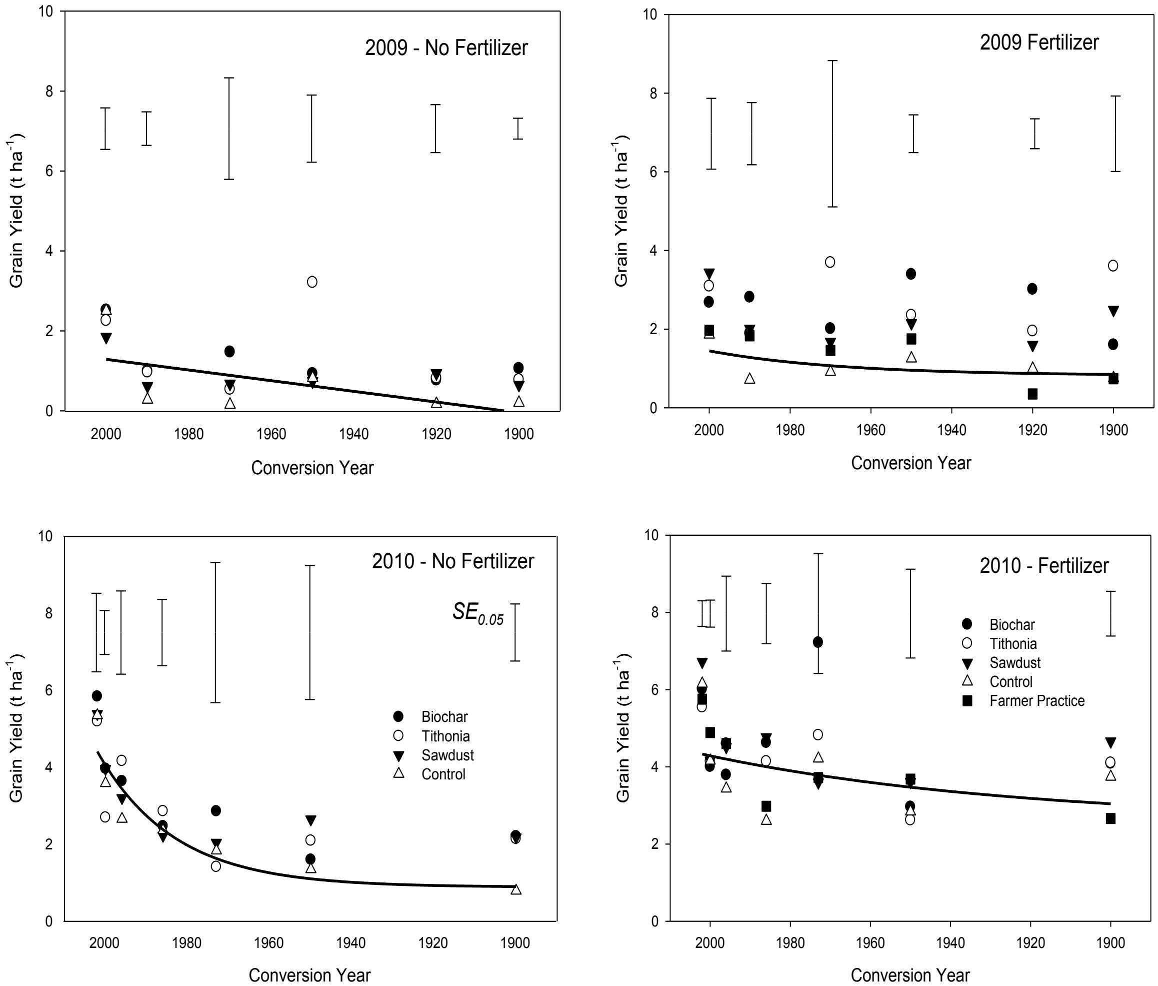

Figure 2.2. Residual effects of organic matter additions of contrasting quality on soil productivity (maize grain yield) along a chronosequence of soil fertility degradation with or without fertilization during the long-rain seasons of 2009 and 2010. Organic matter additions are compared relative to the control and farmer practice plots. Bars are standard error ($P < 0.05$, $N = 3$). Regressions are for control plots only: 2009 no fertilizer ($r^2 = 0.32$, $P = 0.95$), fertilizer ($r^2 = 0.31$, $P = 0.96$). 2010 no fertilizer ($r^2 = 0.87$, $P = 0.24$), fertilizer ($r^2 = 0.16$, $P = 0.97$).

Clear long-term trends appeared as a result of organic input treatments (Fig. 3). All organic inputs were added on three occasions: long-rains of 2005, short-rains of 2005, and the long-rains of 2006 (arrows in Fig. 3). With tithonia, maize grain yields increased following each application with the greatest yield achieved after the third application (9.4 t ha^{-1}) (long-rains of 2006). After applications ceased yields rapidly declined. Maize grain yields increased with biochar applications relative to the control, however, yield increases were substantially less than tithonia. Unlike tithonia, biochar yields maintained a relative constant positive yield difference with respect to the control.

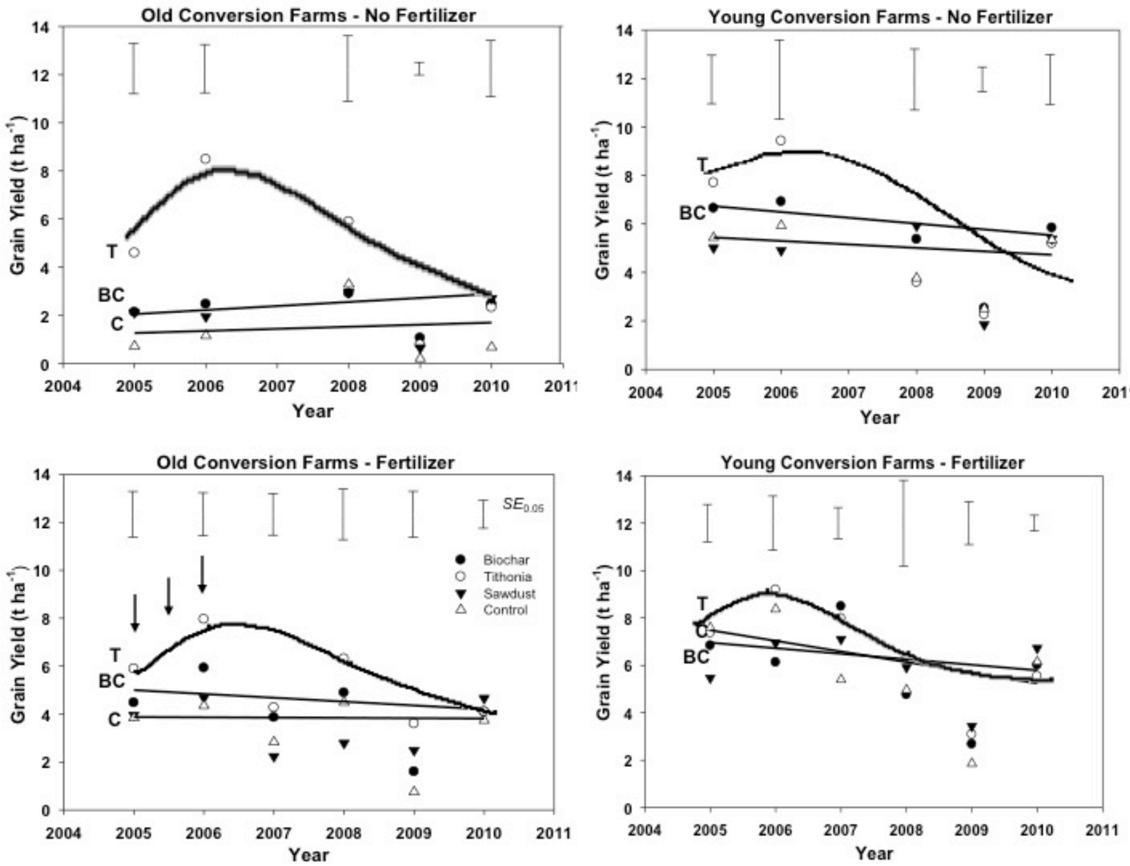

Figure 2.3. Long-term yield dynamics following the additions of organic inputs of contrasting quality and the residual effects after cessation of input additions on a high and low fertility soil. Organic input additions occurred in 2005 and 2006 only (arrows). Data from the year 2009 not included in dynamic lines due to severe drought conditions. Bars represent standard error ($P < 0.05$, $N = 3$).

Fertilizer additions did not affect the shape of the yield responses to organic amendments, rather, the addition of fertilizer increased the magnitude of the yield at relatively constant rates in all years (Fig. 3). Yield response to fertilization was not observed in the young conversions, while yields increased by 61% in farms converted for 80 years or more. Yields remained relatively stable for the biochar and control plots in soils of old conversions (greater than 80 years). In 2005, yields for the biochar and control plots were 2.13 and 0.72 t ha^{-1} without fertilizer and 4.50 and 3.84 t ha^{-1} with fertilizer, respectively. In 2010, yield for the biochar and control plots were 2.48 and 0.68 t ha^{-1} without fertilizer and 4.08 and 3.74 t ha^{-1} with fertilizer, respectively. In contrast, yields decreased for both the biochar and control plots in the young conversions. In 2005, yields for the biochar and control plots were 6.65 and 5.43 t ha^{-1} without fertilizer and 6.83 and 7.59 t ha^{-1} with fertilizer, respectively. In 2010, yield for the biochar and control plots were 5.84 and 5.35 t ha^{-1} without fertilizer and 6.01 and 6.15 t ha^{-1} with fertilizer, respectively.

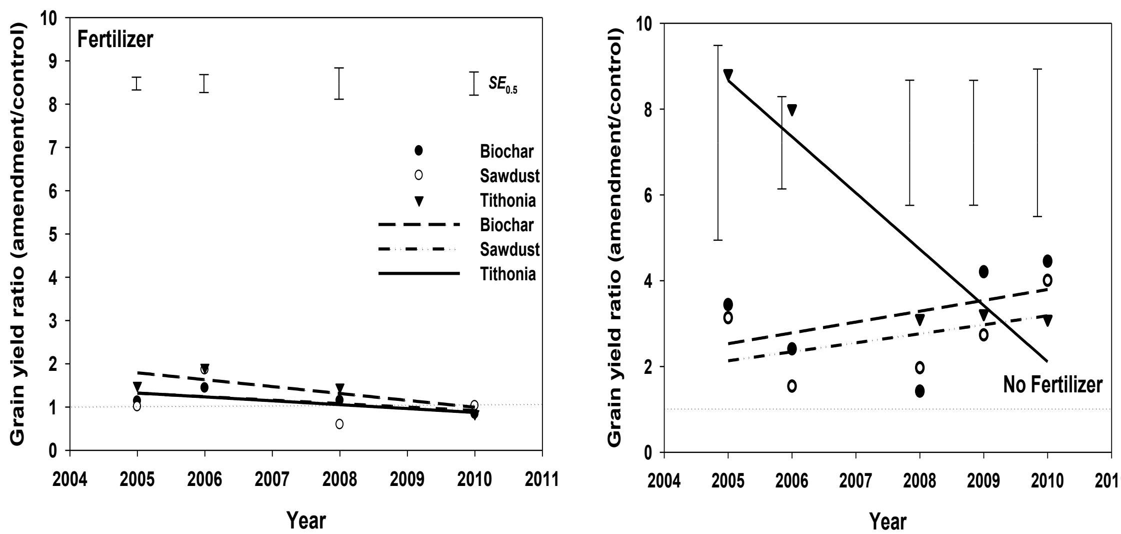

Figure 2.4. Residual effects of applications of organic amendments of contrasting quality on maize grain yield. Y-axis is the ratio of maize grain yield (t ha^{-1}) of the organic amendment to the control. Data is from farms converted to agriculture in the year 1900. Fertilizer: Biochar r^2 = 0.64, P = 0.20; Sawdust r^2 = 0.52, P = 0.27; Tithonia r^2 = 0.14, P = 0.62. No fertilizer: Biochar r^2 = 0.0.17 P = 0.49; Sawdust r^2 = 0.20 P = 0.45; Tithonia r^2 = 0.88 P = 0.019.

In the farms converted in the year 1900, the ratio of maize grain yields between the amendments and the control were not significantly different between any treatments among the fertilized plots for any year (Fig. 4). However, without fertilization in 2005 and 2006 (the organic amendment applications years) adding tithonia resulted in greater maize yield (P < 0.05) (ratio of 8.83 and 8.01, respectively) than adding biochar (3.44 and 2.41, respectively) or sawdust (3.14 and 1.54, respectively). After additions ended, there were no significant differences. The slope for the tithonia plot in the non-fertilized treatments was negative ($P = 0.019$) while the sawdust and biochar plots did not have significant slopes ($P = 0.20$ and 0.49, respectively).

Abscisic acid

ABA levels did not change between organic input treatments ($P > 0.05$). However, conversion year ($P < 0.0001$), fertilizer ($P = 0.0001$) and the interaction between fertilizer and conversion year ($P < 0.0001$) significantly affected ABA levels (Fig. 5). Fertilization significantly increased concentration of ABA in the plant tissues from 2.21-5.69 pmol g^{-1} without fertilization to 2.77-11.84 pmol g^{-1} with fertilization. In the unfertilized maize, ABA levels did not significantly change with conversion age. In the fertilized plots, ABA concentration remained constant in the early conversion ages but significantly increased in the farms converted in the oldest conversion ages (1920 - 1900).

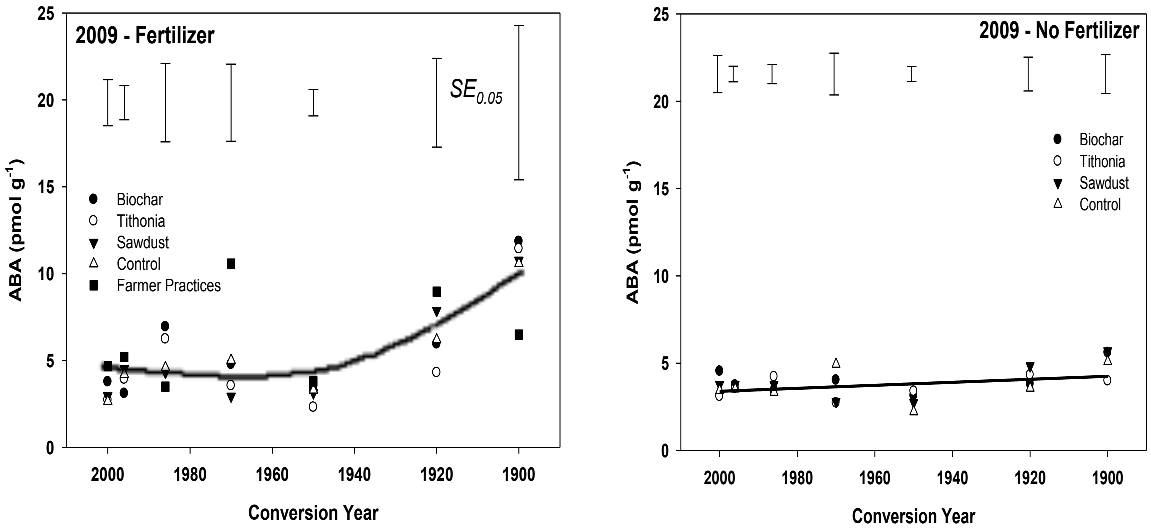

Figure 2.5. ABA concentration in maize tissue as influenced by farm conversion age, fertilization, and organic input quality. Data is from three sampling dates taken during early, mid, and late grain-filling stages for the long-rains of 2009. Regression is calculated for control plots. Bars represent standard error ($P < 0.05$, $N = 9$).

Discussion

Organic input quality affected the short-term and residual maize yield dynamics along a chronosequence of land degradation. In the short-term, the large improvement in yield response after tithonia additions not seen with biochar is mostly ascribed to substantially greater N addition with tithonia. Annual application rates of tithonia-derived N were 1294.4 kg ha^{-1} yr^{-1} while annual application rates of biochar-derived N were 31 kg ha^{-1} yr^{-1} (Kimetu et al., 2008). In addition, very little is known about the availability of biochar-derived N (Chan and Xu, 2009), but is likely to be very low even with biochar containing larger proportions of N (Gaskin et al., 2010). It is possible that the majority of N found in biochar is in a chemically recalcitrant form that is unavailable to plants (Knicker et al., 2006), at least in the short-term (Bridle and

Pritchard, 2004). As previous studies had found N to be the most limiting nutrient in the studied soils (Ngoze et l., 2008), this large difference in N application would have profound effects on maize yields.

After organic inputs were stopped, maize yields with tithonia additions declined. Jama et al. (2000) found that half of the C added to the soil from tithonia mineralized in two weeks, and 80% after two years (Kimetu and Lehmann, 2010). As the N in tithonia is mostly in the organic form, the mineralization of the biomass C would release N into the mineral pool which would be either taken up by the plants, lost via leaching and denitrification, or remain in some form in the soil (i.e. bound to exchange sites as NH_4^+ or remaining in organic form). The dramatic yield decline indicates a large proportion of the N was unavailable for subsequent crops after tithonia inputs ended.

Any improvements in grain yield due to tithonia additions rapidly declined with total residual yield losses of 45% from 2005 to 2010 (Fig. 4). In addition, no differences were found with the control after applications of tithonia stopped. In 2009 the yield ratios between tithonia, biochar and sawdust intersected at around 3. This clearly indicates that the yield improvements following tithonia additions are substantial, but unless the applications are maintained yields will quickly decline, while yield increases with more recalcitrant materials are more stable.

While biochar additions did not increase the maize yields above the control to the same extent as tithonia, biochar additions helped maintain a relatively consistent yield improvement for the duration of the study period (Fig. 1). Since N was not applied in appreciable quantities with biochar as mentioned above, other crop-limiting soil properties must have been altered by biochar additions. Soil applications of biochar have been demonstrated to alleviate soil acidity, improve soil physical characteristics (Glaser, 2002), alter nutrient retention (Lehmann et al., 2003; Major et al., 2009, 2010) and soil microbial abundance and community structure (Warnock et al., 2007; Thies and Rillig, 2009; Lehmann et al., 2011). Any one or a combination of these mechanisms could have resulted in the observed yield trends with biochar, while the trends are not significant, a few more seasons of data would be needed to verify. In addition, the mechanisms for this experiment are not sufficiently clear and warrant further research.

The potential for soil fertility amelioration is greater on the older farms and more degraded soils (Solomon et al., 2007; Ngoze et al., 2008; Moebius-Clune et al., 2011), both in respect to nutrient constraints (i.e. N response) and soil physical properties constraints (e.g. infiltration, available water-holding capacity). Previous studies on these soils found bulk density increases with conversion age (Kinyangi, 2008). In addition, Moebius-Clune et al. (2011) found that as conversion age increases, available water-holding capacity and water-stable aggregation decreases. This response is directly correlated to soil C contents (Kinyangi, 2008, Moebius-Clune et al., 2011). As a result, maize on older farms experienced proportionally greater water stress (Fig. 4). These constraints were largely absent in the younger conversion farms, which showed no differences between the various organic treatments, either fertilized or unfertilized (Fig. 1).

Yields over the six-year study period remained fairly constant in the old conversions, while in the recent conversions the slope was negative even for the control without organic amendments (Fig. 3). In the old conversion sites, soil fertility degradation appears to have reached equilibrium and the levels of soil C and N have stabilized to the biophysical and environmental conditions of the area for the time period studied here (Solomon et al., 2007). In the young conversion sites yields continue to decline as high levels of soil C are mineralized to release available nutrients previously held in the organic form (Grace et al., 1995; Lal, 2006). Biochar seems to have slowed the yield decline relative to the control. As biochar is thought to be biochemically much more resistant to microbial degradation than uncharred organic amendments (Lehmann et al., 2009), any beneficial effect of organic matter amendments of biochar last longer than those by more labile organic matter such as tithonia. In 2010 there were no significant differences between organic amendments. A few more years of data will be needed to determine if equilibrium yield levels have been achieved between amendments or if yields from the tithonia treatment will continue to decline.

Fertilizer additions had the greatest effects in the older conversion farms and did not alter yields in the farms recently converted from forest. Stocks of soil N at the sites recently converted from forest were found to be 7.2 t N ha^{-1} in the topsoil (Kinyangi, 2008) with a mineralization rate of 511 kg N ha^{-1} yr^{-1} (Ngoze, 2008); at this level of soil N mineralization the 120 kg N ha^{-1} added as mineral fertilizer may not improve plant N nutrition.

Conclusions

Applications of organic residues can temporarily increase yields following intensive cropping after land conversion of the studied natural ecosystems in western Kenya. Residue quality has effects on both the short-term and residual yield dynamics. In the short-term, applications of N-rich green manure can increase agricultural productivity several fold. However, after stopping input of such high-quality residue, yields rapidly decline. Applications of the much more recalcitrant biochar also increased yields in the short-term relative to the control (albeit at a lower level than with tithonia green manure if the soil is limiting in N), however, the sharp yield decline after cessation of amendment application was not seen.

Sustainable land management in degraded soils of SSA must include a focus on improving the soil C status in conjunction with nutrient additions through commercial mineral fertilizers or organic amendments. This study indicates that yield improvements can be realized over the long term by increasing the stocks of soil organic C through additions of stable forms of low quality organic inputs which are not related to nutrient additions. How this dynamic will affect nutrient fluxes in the long-term is not known and warrants further research.

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APPENDIX

Data table for chapter 1, Table 1.2 & 1.3

Biochar application type	Biochar	Fertilizer	Plot number	Grain yield (t/ha)	Stover yield (t/ha)	Year
	0	90	4	4.393823178	7.426594982	2007
	0	90	8	5.029964158	8.896111111	2007
	0	90	16	4.787043011	7.829510155	2007
	3	90	6	4.681630824	8.683143369	2007
	3	90	10	3.954924731	7.430988053	2007
	3	90	35	3.688369176	6.635403823	2007
	12	90	1	3.700119474	5.857548387	2007
	12	90	13	3.968391876	8.146467742	2007
	12	90	29	4.902485066	8.754057945	2007
	30	90	14	3.120256272	5.792305854	2007
	30	90	27	4.767096774	6.050059737	2007
	30	90	36	4.182353644	7.83894086	2007
	12	50	5	3.536086022	8.021721027	2007
	12	50	19	2.239784946	4.966117085	2007
	12	50	28	4.379032258	8.32172043	2007
	12	70	12	2.912700119	2.658333333	2007
	12	70	17	3.096774194	6.128213859	2007
	12	70	33	4.125688769	4.738064516	2007
	12	100	9	4.491775388	8.6300454	2007
	12	100	21	5.400726404	9.535645161	2007
	12	100	23	4.082768817	7.691028674	2007
	0	50	15	5.803225209	8.291526882	2007
	0	50	30	4.436109916	7.182311828	2007
	0	50	34	6.730645161	9.440382318	2007
	0	70	7	4.378404421	7.890107527	2007
	0	70	20	4.94666129	9.572258065	2007
	0	70	24	3.479985066	6.585677419	2007
	0	100	3	4.045892473	8.145913978	2007
	0	100	25	4.100870968	7.207321386	2007
	0	100	22	5.338709677	10.45212903	2007
Per year	1	90	11	4.445512545	7.346666667	2007
Per year	1	90	18	3.816172043	7.464577658	2007
Per year	1	90	31	3.87483871	6.508791517	2007
Banded	3	90	2	3.220839307	6.206021505	2007
Banded	3	90	26	3.726354241	6.83082497	2007
Banded	3	90	32	4.606451613	7.900379331	2007
	0	90	4	8.142222222	13.50089606	2008
	0	90	8	10.18012545	15.07795699	2008
	0	90	16	9.450537634	12.15507766	2008

	3	90	6	8.272019116	13.68960573	2008
	3	90	10	6.873727599	11.3297491	2008
	3	90	35	8.241397849	13.26487455	2008
	12	90	1	9.373560335	12.72043011	2008
	12	90	13	6.179880526	10.2	2008
	12	90	29	8.878996416	13.06630824	2008
	30	90	14	8.162222222	10.42389486	2008
	30	90	27	7.75078853	12.48811231	2008
	30	90	36	7.054193548	10.1390681	2008
	12	50	5	7.515531661	11.18124253	2008
	12	50	19	5.536117085	8.559139785	2008
	12	50	28	7.430913978	12.15197133	2008
	12	70	12	8.149342891	11.15143369	2008
	12	70	17	7.361373955	9.86260454	2008
	12	70	33	9.317377539	14.120908	2008
	12	100	9	10.03575269	13.54575866	2008
	12	100	21	12.0438172	14.69623656	2008
	12	100	23	12.06693548	12.95728793	2008
	0	50	15	7.203727599	10.61792115	2008
	0	50	30	6.930346476	9.688769415	2008
	0	50	34	6.821421744	12.19784946	2008
	0	70	7	8.255125448	14.41648746	2008
	0	70	20	7.496129032	11.40561529	2008
	0	70	24	6.359904421	12.93204301	2008
	0	100	3	14.21509558	13.18996416	2008
	0	100	25	7.336200717	13.01415771	2008
	0	100	22	9.687419355	14.99103943	2008
Per year	1	90	11	8.229988053	11.90770609	2008
Per year	1	90	18	7.720692951	11.46666667	2008
Per year	1	90	31	6.487741935	10.55878136	2008
Banded	3	90	2	7.010872162	12.2921147	2008
Banded	3	90	26	6.971206691	11.22580645	2008
Banded	3	90	32	7.391039427	13.87455197	2008
	0	90	4	9.116750299	14.12903226	2009
	0	90	8	9.008172043	13.72998805	2009
	0	90	16	6.712228196	10.38225806	2009
	3	90	6	8.857168459	12.25537634	2009
	3	90	10	7.025716846	9.416666667	2009
	3	90	35	7.040023895	14.07885305	2009
	12	90	1	6.601338112	10.22060932	2009
	12	90	13	7.615770609	13.58924731	2009
	12	90	29	9.443046595	13.61923536	2009
	30	90	14	7.339456392	8.444623656	2009
	30	90	27	6.368243728	9.070071685	2009
	30	90	36	7.270322581	13.29784946	2009

	12	50	5	5.312724014	7.508721625	2009
	12	50	19	5.497132616	8.006451613	2009
	12	50	28	8.217096774	11.20334528	2009
	12	70	12	7.754193548	12.02897252	2009
	12	70	17	7.065483871	8.811827957	2009
	12	70	33	8.436630824	15.18936679	2009
	12	100	9	9.646774194	13.15173238	2009
	12	100	21	11.76211171	14.81971326	2009
	12	100	23	11.33019713	12.36774194	2009
	0	50	15	6.289032258	8.377001195	2009
	0	50	30	6.38739546	9.917921147	2009
	0	50	34	6.686845878	10.73626045	2009
	0	70	7	7.937096774	11.97968937	2009
	0	70	20	7.810752688	13.04348865	2009
	0	70	24	7.063154122	10.64038232	2009
	0	100	3	8.195531661	12.51146953	2009
	0	100	25	7.280692951	10.73058542	2009
	0	100	22	8.930645161	12.46594982	2009
Per year	1	90	11	8.167586619	11.25041816	2009
Per year	1	90	18	7.553691756	12.11899642	2009
Per year	1	90	31	7.876182796	12.98924731	2009
Banded	3	90	2	8.981792115	12.34086022	2009
Banded	3	90	26	6.709802867	10.80860215	2009
Banded	3	90	32	10.65915771	15.3958184	2009
	0	90	4	8.621266428	13.82676225	2010
	0	90	8	8.185902031	11.92258065	2010
	0	90	16	9.25646356	13.13978495	2010
	3	90	6	8.041051374	13.45364397	2010
	3	90	10	9.186947431	13.70197133	2010
	3	90	35	8.579814815	12.53924731	2010
	12	90	1	8.197013142	12.34378734	2010
	12	90	13	7.993333333	13.33333333	2010
	12	90	29	9.670005974	13.57258065	2010
	30	90	14	7.427598566	11.3948626	2010
	30	90	27	8.088387097	10.99193548	2010
	30	90	36	7.900806452	10.59593787	2010
	12	50	5	7.4190681	11.33870968	2010
	12	50	19	6.907891278	9.809020311	2010
	12	50	28	7.896869773	11.54121864	2010
	12	70	12	8.615770609	12.02897252	2010
	12	70	17	7.740979689	10.39354839	2010
	12	70	33	8.348094385	11.03942652	2010
	12	100	9	8.120997611	12.11469534	2010
	12	100	21	9.497849462	14.67658303	2010
	12	100	23	9.212777778	12.73566308	2010

	0	50	15	7.832502987	10.46487455	2010
	0	50	30	7.097580645	11.2181601	2010
	0	50	34	6.950238949	10.70131422	2010
	0	70	7	8.243154122	11.53942652	2010
	0	70	20	8.450698925	12.15316607	2010
	0	70	24	8.568040621	11.70442055	2010
	0	100	3	8.830681004	12.13160096	2010
	0	100	25	8.39874552	12.01481481	2010
	0	100	22	9.590250896	13.2776583	2010
1/yr	1	90	11	8.726827957	12.90985663	2010
1/yr	1	90	18	7.897491039	10.0353644	2010
1/yr	1	90	31	10.62761649	13.30752688	2010
Banded	3	90	2	7.315412186	11.57311828	2010
Banded	3	90	26	7.909253286	12.55011947	2010
Banded	3	90	32	10.6922043	14.00800478	2010

Data table for chapter 1, Table 1.4

Year	Total plant N uptake (kg/ha)	Fertilizer (%)	Biochar (%)	Plot number	Tissue N concentration (mg/g)
2007	-	50	0	15	0
2007	43.86632844	50	0	30	6.107549977
2007	67.51919557	50	0	34	7.152167497
2007	55.22194687	50	12	5	6.884052272
2007	26.85559313	50	12	19	5.407764792
2007	57.74534046	50	12	28	6.939110842
2007	72.35216667	100	0	3	8.882019484
2007	77.35372176	100	0	22	7.40076223
2007	56.61536427	100	0	25	7.855257347
2007	62.38198812	100	12	9	7.228465811
2007	63.89992761	100	12	21	6.701164581
2007	49.77698358	100	12	23	6.472083994
2008	74.43891612	50	0	15	7.01068647
2008	69.54836733	50	0	30	7.178245694
2008	90.79178557	50	0	34	7.443261687
2008	96.80052592	50	12	5	8.657403293
2008	60.7037909	50	12	19	7.092277077
2008	83.82637301	50	12	28	6.898170738
2008	120.0675549	100	0	3	9.102947773
2008	131.1965241	100	0	22	8.751662934
2008	97.3871756	100	0	25	7.48317162
2008	118.3612791	100	12	9	8.737884831
2008	123.1696971	100	12	21	8.381036643
2008	107.3035271	100	12	23	8.281326131
2009	66.13780192	50	0	15	7.895164437
2009	70.79182797	50	0	30	7.137768784
2009	81.72217382	50	0	34	7.611791291
2009	61.71153321	50	12	5	8.2186471
2009	60.96536674	50	12	19	7.614530093
2009	85.97909013	50	12	28	7.674412238
2009	123.448461	100	0	3	9.866823448
2009	113.3751816	100	0	22	9.094788861
2009	100.0195447	100	0	25	9.320977442
2009	118.4386196	100	12	9	9.005552742
2009	138.5518483	100	12	21	9.349158505
2009	107.7557327	100	12	23	8.712644012

Data table for chapter 1, Table 1.5

Biochar	Fertilizer	Plot number	Maize nitrogen derived from fertilizer (kg/ha)	Maize delta 15N
12	50	5	24.65	1656.13
12	50	19	16.80	1146.74
12	50	28	25.50	1229.76
12	100	9	68.54	1323.57
12	100	21	60.61	1000.68
12	100	23	52.03	1105.19
0	50	15	21.34	1339.84
0	50	30	22.37	1312.21
0	50	34	13.65	694.59
0	100	3	61.73	1144.12
0	100	25	57.91	910.79
0	100	22	45.13	1324.98

Data table for chapter 1, Table 1.5

Biochar	**Fertilizer**	**Plot number**	**15N (kg/ha)**	**Nitrogen derived from fertilizer (kg/ha)**	**Delta 15N**	**Total microbial biomass N (mg/g)**
0	50	15	0.000637	0.04	74.70	0.02
0	50	30	0.000490	0.03	47.18	0.06
0	50	34	0.003275	0.22	130.35	0.06
12	50	5	0.000620	0.04	47.00	0.03
12	50	19	0.000031	0.00	12.45	0.06
12	50	28	0.005314	0.35	339.87	0.10
0	100	3	0.001541	0.18	138.17	0.04
0	100	22	0.000349	0.04	49.12	0.07
0	100	25	0.000516	0.06	60.26	0.08
12	100	9	0.002816	0.34	202.84	0.04
12	100	21	0.001212	0.15	107.39	0.14
12	100	23	0.003563	0.43	302.83	0.06

Data table for chapter 1, Table 1.5

Biochar (t/ha)	**Fertilizer (%)**	**Plot number**	**N mineralization (kg N/ha*day)**
0	100	3	-
0	100	3	10.76
0	100	3	2.15
0	100	3	1.46
0	100	3	1.24
0	100	3	0.94
0	100	3	1.12
0	100	3	1.12
12	50	5	-
12	50	5	0.31
12	50	5	0.06
12	50	5	0.13
12	50	5	0.63
12	50	5	0.51
12	50	5	0.71
12	50	5	0.78
12	100	9	-
12	100	9	0
12	100	9	0.33
12	100	9	0.20
12	100	9	0.24
12	100	9	0.23
12	100	9	0.28
12	100	9	0.39
0	50	15	-
0	50	15	28.20
0	50	15	5.64
0	50	15	3.56
0	50	15	2.61
0	50	15	1.88
0	50	15	1.70
0	50	15	1.48
12	50	19	-
12	50	19	21.79
12	50	19	4.36
12	50	19	2.94
12	50	19	2.08
12	50	19	1.49

12	50	19	1.39
12	50	19	1.25
12	100	21	-
12	100	21	17.46
12	100	21	3.54
12	100	21	2.08
12	100	21	1.73
12	100	21	1.28
12	100	21	1.23
12	100	21	1.10
0	100	22	-
0	100	22	13.34
0	100	22	2.91
0	100	22	1.75
0	100	22	1.77
0	100	22	1.36
0	100	22	1.32
0	100	22	1.30
12	100	23	-
12	100	23	25.47
12	100	23	5.12
12	100	23	3.10
12	100	23	2.42
12	100	23	1.74
12	100	23	1.44
12	100	23	1.32
0	100	25	-
0	100	25	16.14
0	100	25	3.23
0	100	25	2.03
0	100	25	1.60
0	100	25	1.13
0	100	25	1.11
0	100	25	1.06
12	50	28	-
12	50	28	20.80
12	50	28	4.16
12	50	28	2.50
12	50	28	2.09
12	50	28	1.54
12	50	28	1.35
12	50	28	1.25

0	50	30	-
0	50	30	4.50
0	50	30	0.90
0	50	30	0.68
0	50	30	0.79
0	50	30	0.64
0	50	30	0.56
0	50	30	0.56
0	50	34	-
0	50	34	41.89
0	50	34	8.38
0	50	34	5.04
0	50	34	3.57
0	50	34	2.55
0	50	34	2.15
0	50	34	1.86

Data table for chapter 1, Table 1.5; Figure 1.5

Plot number	Ceq DON (mg-N/L)	q DON (mg/g)	Kd (mg/L)	Biochar (t/ha)	Fertilizer (%)
3	0.73	-0.0007	-0.0010	0	100
3	-0.35	0.0023	-0.0064	0	100
3	-0.76	0.0039	-0.0051	0	100
3	0.02	0.0031	0.1456	0	100
3	0.42	0.0038	0.0091	0	100
3	-1.35	0.0089	-0.0066	0	100
3	4.34	0.0006	0.0001	0	100
3	1.87	0.0087	0.0046	0	100
3	2.53	0.0104	0.0041	12	50
5	-0.34	0.0022	-0.0065	12	50
5	0.17	0.0020	0.0114	12	50
5	0.69	0.0017	0.0025	12	50
5	-0.09	0.0048	-0.0527	12	50
5	-0.28	0.0068	-0.0241	12	50
5	0.51	0.0083	0.0161	12	50
5	1.54	0.0093	0.0061	12	50
5	1.67	0.0122	0.0073	12	50
9	-0.43	0.0016	-0.0038	12	100
9	0.15	0.0012	0.0083	12	100
9	-1.12	0.0046	-0.0041	12	100
9	-1.06	0.0052	-0.0049	12	100
9	-0.70	0.0061	-0.0087	12	100
9	0.01	0.0062	0.6180	12	100
9	0.93	0.0074	0.0080	12	100
9	1.86	0.0087	0.0047	12	100
9	1.99	0.0115	0.0058	12	100
15	2.28	-0.0038	-0.0017	0	50
15	1.57	-0.0016	-0.0010	0	50
15	2.27	-0.0022	-0.0010	0	50
15	1.91	-0.0007	-0.0004	0	50
15	1.94	0.0008	0.0004	0	50
15	1.97	0.0023	0.0011	0	50
15	3.06	0.0032	0.0010	0	50
15	3.46	0.0055	0.0016	0	50
15	3.74	0.0080	0.0021	0	50
19	0.76	-0.0008	-0.0010	12	50
19	0.26	0.0010	0.0041	12	50
19	1.25	-0.0002	-0.0001	12	50

19	0.90	0.0013	0.0014	12	50
19	1.44	0.0018	0.0012	12	50
19	1.15	0.0039	0.0034	12	50
19	2.73	0.0069	0.0025	12	50
19	3.83	0.0078	0.0021	12	50
21	2.38	-0.0040	-0.0017	12	100
21	2.90	-0.0042	-0.0015	12	100
21	-0.29	0.0029	-0.0100	12	100
21	1.61	-0.0001	-0.0001	12	100
21	1.58	0.0015	0.0009	12	100
21	2.65	0.0009	0.0003	12	100
21	2.29	0.0047	0.0021	12	100
21	2.78	0.0068	0.0025	12	100
21	3.30	0.0089	0.0027	12	100
22	-0.92	0.0026	-0.0028	0	100
22	-1.09	0.0037	-0.0034	0	100
22	-0.40	0.0031	-0.0078	0	100
22	-0.32	0.0037	-0.0118	0	100
22	-0.03	0.0063	-0.1958	0	100
22	0.44	0.0084	0.0192	0	100
22	1.39	0.0096	0.0069	0	100
22	1.77	0.0120	0.0067	0	100
23	0.54	-0.0003	-0.0006	12	100
23	0.92	-0.0003	-0.0003	12	100
23	0.79	0.0008	0.0010	12	100
23	4.99	-0.0069	-0.0014	12	100
23	0.95	0.0028	0.0029	12	100
23	0.95	0.0043	0.0045	12	100
23	1.81	0.0057	0.0031	12	100
23	3.14	0.0061	0.0020	12	100
23	4.46	0.0066	0.0015	12	100
25	0.23	0.0003	0.0013	0	100
25	0.71	0.0001	0.0002	0	100
25	0.49	0.0014	0.0028	0	100
25	0.91	0.0013	0.0014	0	100
25	1.65	0.0014	0.0008	0	100
25	1.70	0.0028	0.0017	0	100
25	1.59	0.0061	0.0038	0	100
25	2.01	0.0084	0.0042	0	100
25	1.73	0.0121	0.0070	0	100
28	0.12	0.0005	0.0041	12	50
28	0.17	0.0012	0.0071	12	50

28	0.09	0.0021	0.0227	12	50
28	0.24	0.0026	0.0112	12	50
28	0.61	0.0035	0.0057	12	50
28	0.67	0.0049	0.0073	12	50
28	1.69	0.0059	0.0035	12	50
28	2.02	0.0084	0.0041	12	50
28	2.54	0.0104	0.0041	12	50
30	0.87	-0.0010	-0.0011	0	50
30	0.61	0.0003	0.0005	0	50
30	1.18	0.0000	0.0000	0	50
30	0.19	0.0027	0.0145	0	50
30	0.44	0.0038	0.0087	0	50
30	0.60	0.0050	0.0083	0	50
30	0.78	0.0078	0.0100	0	50
30	2.02	0.0084	0.0041	0	50
30	1.19	0.0131	0.0110	0	50
34	0.07	0.0006	0.0090	0	50
34	0.40	0.0008	0.0019	0	50
34	1.48	-0.0006	-0.0004	0	50
34	1.29	0.0005	0.0004	0	50
34	2.04	0.0006	0.0003	0	50
34	1.34	0.0035	0.0026	0	50
34	2.26	0.0048	0.0021	0	50
34	2.14	0.0081	0.0038	0	50
34	2.34	0.0108	0.0046	0	50

Data from chapter 1, Figure 1.1

Plot number	Depth (cm)	Sample ID	Biochar rate (t/ha)	Fertilizer rate (%)	NH_4 (kg/ha)	NO_3+NO_2 (kg/ha)
3	0-10	1	0	100	1.54	4.66
3	10-20	2	0	100	1.54	4.66
3	20-30	3	0	100	1.38	8.06
3	30-40	4	0	100	1.49	6.35
3	40-50	5	0	100	1.22	5.19
3	50-60	6	0	100	36.99	9.37
5	0-10	7	12	50	3.65	5.43
5	10-20	8	12	50	1.26	6.91
5	20-30	9	12	50	0.68	7.06
5	30-40	10	12	50	0.74	4.65
5	40-50	11	12	50	0.86	3.65
5	50-60	12	12	50	1.39	5.25
9	0-10	13	12	100	3.44	2.16
9	10-20	14	12	100	2.58	5.12
9	20-30	15	12	100	1.40	9.53
9	30-40	16	12	100	0.20	6.48
9	40-50	17	12	100	0.47	6.85
9	50-60	18	12	100	2.51	2.56
15	0-10	19	0	50	0.06	1.30
15	10-20	20	0	50	0.79	2.36
15	20-30	21	0	50	0.43	4.79
15	30-40	22	0	50	0.15	4.33
15	40-50	23	0	50	0.06	3.01
15	50-60	24	0	50	0.07	2.11
19	0-10	25	12	50	0.06	2.83
19	10-20	26	12	50	1.34	2.24
19	20-30	27	12	50	1.30	7.44
19	30-40	28	12	50	1.49	5.19
19	40-50	29	12	50	1.18	6.73
19	50-60	30	12	50	1.10	12.02
21	0-10	31	12	100	0.06	5.49
21	10-20	32	12	100	0.59	2.83
21	20-30	33	12	100	1.19	9.34
21	30-40	34	12	100	2.18	7.04
21	40-50	35	12	100	0.86	7.47
21	50-60	36	12	100	0.13	5.21
22	0-10	37	0	100	0.06	3.97
22	10-20	38	0	100	1.29	3.65

22	20-30	39	0	100	2.19	9.29
22	30-40	40	0	100	1.96	9.09
22	40-50	41	0	100	0.76	6.02
22	50-60	42	0	100	0.07	3.17
23	0-10	43	12	100	10.59	11.21
23	10-20	44	12	100	5.23	6.05
23	20-30	45	12	100	7.46	16.46
23	30-40	46	12	100	3.45	9.93
23	40-50	47	12	100	1.90	7.74
23	50-60	48	12	100	1.35	6.87
25	0-10	49	0	100	1.02	3.78
25	10-20	50	0	100	2.66	4.49
25	20-30	51	0	100	3.13	7.85
25	30-40	52	0	100	2.62	7.75
25	40-50	53	0	100	0.64	4.25
25	50-60	54	0	100	0.56	3.64
28	0-10	55	12	50	1.31	3.88
28	10-20	56	12	50	3.02	7.70
28	20-30	57	12	50	2.76	8.72
28	30-40	58	12	50	1.56	6.09
28	40-50	59	12	50	1.90	8.78
28	50-60	60	12	50	-	-
30	0-10	61	0	50	0.96	5.85
30	10-20	62	0	50	0.71	2.01
30	20-30	63	0	50	3.25	7.89
30	30-40	64	0	50	3.31	6.94
30	40-50	65	0	50	1.40	5.13
30	50-60	66	0	50	0.94	2.99
34	0-10	67	0	50	0.47	2.62
34	10-20	68	0	50	4.87	8.14
34	20-30	69	0	50	2.12	6.34
34	30-40	70	0	50	1.85	7.03
34	40-50	71	0	50	2.01	7.88
34	50-60	72	0	50	1.57	5.37

Data table from chapter 1, Figure 1.2

Plot number	Biochar rate (t/ha)	Fertilizer (%)	Depth (cm)	$\delta^{15}N$ (‰)	Nitrogen derived from fertilizer (kg/ha)
3	0	100	10.00	31.96	17.84
22	0	100	10.00	12.12	4.16
25	0	100	10.00	15.78	7.33
3	0	100	20.00	7.52	-0.80
22	0	100	20.00	10.00	2.60
25	0	100	20.00	11.95	4.95
3	0	100	30.00	7.34	-0.87
22	0	100	30.00	8.72	0.61
25	0	100	30.00	9.70	1.74
3	0	100	40.00	8.43	0.18
22	0	100	40.00	8.83	0.70
25	0	100	40.00	17.42	2.22
3	0	100	50.00	10.32	1.15
22	0	100	50.00	12.07	1.11
25	0	100	50.00	16.39	7.11
3	0	100	60.00	9.02	0.20
22	0	100	60.00	7.04	-0.39
25	0	100	60.00	12.66	1.07
9	12	100	10.00	36.36	27.55
21	12	100	10.00	19.70	9.89
23	12	100	10.00	45.80	32.74
9	12	100	20.00	24.69	24.65
21	12	100	20.00	10.50	4.81
23	12	100	20.00	14.33	8.43
9	12	100	30.00	8.39	0.16
21	12	100	30.00	9.80	2.29
23	12	100	30.00	9.41	1.34
9	12	100	40.00	9.46	0.68
21	12	100	40.00	9.82	1.89
23	12	100	40.00	-11.34	-0.76
9	12	100	50.00	11.71	1.33
21	12	100	50.00	11.04	1.81
23	12	100	50.00	11.70	1.86
21	12	100	60.00	11.50	2.12
23	12	100	60.00	-9.89	-0.88
9	12	100	60.00	10.60	0.52
5	12	50	10.00	10.58	1.21
19	12	50	10.00	9.11	0.61

28	12	50	10.00	31.86		17.27
5	12	50	20.00	7.76		-0.32
19	12	50	20.00	8.84		0.74
28	12	50	20.00	15.80		8.37
5	12	50	30.00	9.96		0.88
19	12	50	30.00	8.71		0.46
28	12	50	30.00	9.81		1.35
5	12	50	40.00	8.87		0.28
19	12	50	40.00	8.80		0.58
28	12	50	40.00	9.43		1.38
5	12	50	50.00	16.64		3.90
19	12	50	50.00	8.90		0.87
5	12	50	60.00	13.16		0.48
28	12	50	60.00	11.19		1.11
19	12	50	60.00	9.87		0.65
15	0	50	10.00	14.84		2.92
30	0	50	10.00	13.27		2.40
34	0	50	10.00	26.32		16.85
15	0	50	20.00	9.27		0.74
30	0	50	20.00	9.36		1.15
34	0	50	20.00	11.53		3.02
15	0	50	30.00	8.77		0.30
30	0	50	30.00	9.21		0.80
34	0	50	30.00	9.61		1.30
15	0	50	40.00	9.60		0.31
30	0	50	40.00	9.06		0.62
34	0	50	40.00	9.27		1.23
15	0	50	50.00	11.23		0.55
30	0	50	50.00	19.10		1.55
34	0	50	50.00	9.78		0.94
15	0	50	60.00	10.12		0.64
30	0	50	60.00	11.30		0.75
34	0	50	60.00	9.34	-	

Data table from chapter 1, Table 1.6

Biochar (t/ha)	Fertilizer (%)	Plot number	NH_4 Flux (kg/ha)	NH_4 flow weighted average (mg/l)	NO_3 & NO_2 flux (kg/ha)	NO_3 & NO_2 flow weighted average (mg/l)	Organic N flux (kg/ha)	Organic N flow weighted average (mg/l)
0	100	3	7.35	0.60	2.19	6.96	-5.27	2.36
0	100	3	0.00		5.52		-5.16	
0	100	3	0.00		8.58		-1.31	
0	100	3	0.00		9.74		48.04	
0	100	3	0.00		3.66		19.02	
0	100	3	0.31		23.76		-9.08	
0	100	3	0.18		18.52		-14.77	
0	100	3	0.24		9.15		-7.63	
0	100	3	0.01		2.01		-1.46	
0	100	3	0.03		0.18		6.20	
0	100	3	0.00		0.00		1.45	
0	100	3	0.00		3.90		2.30	
0	100	3	0.00		3.64		-0.05	
0	100	3	0.01		2.66		-0.59	
12	50	5	0.24	0.13	5.70	9.26	-5.95	6.15
12	50	5	0.07		14.30		-12.99	
12	50	5	0.00		4.56		7.34	
12	50	5	0.06		6.52		103.04	
12	50	5	0.30		46.67		-20.21	
12	50	5	0.00		17.88		-5.24	
12	50	5	0.65		0.84		-0.49	
12	50	5	0.00		0.55		-0.02	
12	50	5	0.00		0.05		0.00	
12	50	5	0.00		0.36		-0.08	
12	50	5	0.00		0.09		0.01	
12	50	5	0.00		0.05		0.01	
12	50	9	0.09		0.35		-0.44	
12	100	9	0.06	0.22	0.01	4.14	-0.08	4.23
12	100	9	0.00		6.15		4.65	
12	100	9	0.00		5.33		10.15	
12	100	9	0.72		10.94		1.19	
12	100	9	0.00		0.00		0.08	
12	100	9	0.00		0.00		0.00	
12	100	9	0.47		1.40		4.48	
12	100	9	0.00		0.00		1.89	

12	100	9	0.01		0.22		0.86	
12	100	15	0.00		0.00		1.36	
0	50	15	0.45	0.10	1.24	3.41	-1.05	-0.06
0	50	15	0.01		1.12		1.56	
0	50	15	0.09		0.77		-0.72	
0	50	15	0.06		7.79		-1.64	
0	50	15	0.00		4.59		9.04	
0	50	15	0.01		7.17		-7.18	
0	50	15	0.00		0.00		3.07	
0	50	15	0.41		5.65		-4.98	
0	50	15	0.00		5.13		-3.39	
0	50	15	0.00		0.00		3.38	
0	50	15	0.00		0.00		0.51	
0	50	15	0.00		0.00		0.27	
0	50	19	0.00		0.00		0.57	
12	50	19	0.32	0.16	2.47	9.04	-2.79	-4.91
12	50	19	0.00		0.02		0.01	
12	50	19	1.06		39.51		-30.50	
12	50	19	0.00		4.83		6.74	
12	50	19	0.06		10.32		-1.62	
12	50	19	0.00		4.71		-2.86	
12	50	19	0.00		8.03		-7.41	
12	50	19	0.00		0.00		0.03	
12	50	19	0.01		5.51		-1.37	
12	50	19	0.00		6.41		-5.79	
12	50	19	0.00		0.00		0.40	
12	50	21	0.00		0.12		0.69	
12	100	21	0.71	0.17	10.70	3.41	-5.79	0.33
12	100	21	0.00		0.00		0.00	
12	100	21	0.00		2.36		5.18	
12	100	21	0.01		0.26		-0.19	
12	100	21	0.00		0.00		0.03	
12	100	21	0.00		0.03		-0.02	
12	100	22	0.00		0.90		2.17	
0	100	22	0.65	0.24	4.54	2.81	-2.48	4.88
0	100	22	0.00		0.04		-0.04	
0	100	22	0.00		0.00		9.79	
0	100	22	0.00		2.35		5.91	
0	100	22	0.00		0.53		-0.06	
0	100	22	0.00		0.12		-0.03	
0	100	22	0.00		0.00		0.05	
0	100	23	0.00		0.00		0.12	

12	100	23	0.27	0.10	5.85	1.27	-4.09	0.80
12	100	23	0.01		0.17		-0.06	
12	100	23	0.26		1.35		-0.30	
12	100	23	0.00		2.55		9.52	
12	100	23	0.00		0.00		0.00	
12	100	23	0.26		0.00		0.89	
12	100	23	0.01		0.00		0.20	
12	100	23	0.05		0.07		-0.08	
12	100	23	0.01		0.21		-0.18	
12	100	23	0.00		0.21		-0.19	
12	100	23	0.00		0.00		0.04	
12	100	25	0.00		0.17		0.92	
0	100	25	0.38	1.20	7.81	10.39	-4.93	-4.68
0	100	25	0.00		5.53		-1.50	
0	100	25	13.90		79.17		-79.06	
0	100	25	0.00		5.90		35.64	
0	100	25	0.00		2.96		5.32	
0	100	25	0.27		8.89		-5.11	
0	100	25	0.15		4.08		0.31	
0	100	25	0.00		6.19		-4.96	
0	100	25	0.00		4.18		-2.85	
0	100	25	0.00		2.08		-1.56	
0	100	25	0.00		0.05		0.34	
0	100	25	0.00		0.00		0.03	
0	100	25	0.00		0.00		0.76	
0	100	28	0.00		0.00		0.42	
12	50	28	0.14	0.06	0.00	2.63	-0.14	12.62
12	50	28	0.11		0.11		-0.22	
12	50	28	0.05		2.28		47.25	
12	50	28	0.00		4.78		20.89	
12	50	28	0.00		6.06		-0.19	
12	50	28	0.05		0.35		1.19	
12	50	28	0.00		1.01		-0.32	
12	50	28	0.00		0.00		0.01	
12	50	30	0.00		0.00		1.63	
0	50	30	0.24	0.04	6.53	4.15	-4.54	0.57
0	50	30	0.00		0.04		0.03	
0	50	30	0.00		0.04		-0.01	
0	50	30	0.00		1.85		5.54	
0	50	30	0.00		4.74		6.09	
0	50	30	0.00		8.76		-3.19	

0	50	30	0.00		6.22		-0.25	
0	50	30	0.00		0.22		-0.14	
0	50	30	0.00		0.23		-0.19	
0	50	30	0.00		0.00		0.03	
0	50	30	0.00		0.00		0.03	
0	50	30	0.00		0.00		0.12	
0	50	30	0.00		0.00		0.25	
0	50	34	0.00		0.00		0.17	
0	50	34	0.52	0.08	0.95	3.54	-1.47	0.12
0	50	34	0.00		0.00		1.16	
0	50	34	0.01		1.24		-0.44	
0	50	34	0.00		10.33		-3.08	
0	50	34	0.00		3.03		5.40	
0	50	34	0.00		6.98		-6.98	
0	50	34	0.00		3.82		3.70	
0	50	34	0.00		0.00		2.78	
0	50	34	0.19		0.44		6.36	
0	50	34	0.02		6.34		-6.36	
0	50	34	0.00		0.00		0.00	
0	50		0.00		0.02		0.03	

Data table for chapter 1, Table 1.6

Biochar (t/ha)	Fertilizer (%)	Plot number	Total N Sum of flux (kg/ha)	Total N flow weighted average (mg/l)	$\delta^{15}N$ (‰)	$\delta^{15}N$ flow weighted average (‰)
0.0	100.0	3	133.32	9.93	75.12	13.51
0.0	100.0	3			26.0	
0.0	100.0	3			16.8	
0.0	100.0	3			17.1	
0.0	100.0	3			15.5	
0.0	100.0	3			22.3	
0.0	100.0	3			22.0	
0.0	100.0	3			26.8	
0.0	100.0	3			27.8	
0.0	100.0	3			90.5	
0.0	100.0	3			45.8	
0.0	100.0	3			58.0	
0.0	100.0	3			58.1	
0.0	100.0	3			59.8	
12.0	50.0	5	164.30	18.28		8.21
12.0	50.0	5			15.8	
12.0	50.0	5			17.0	
12.0	50.0	5			15.7	
12.0	50.0	5			15.2	
12.0	50.0	5			15.8	
12.0	50.0	5			20.5	
12.0	50.0	5			19.9	
12.0	50.0	5			18.1	
12.0	50.0	5			47.5	
12.0	50.0	5			18.2	
12.0	50.0	5			24.9	
12.0	100.0	9	49.90	8.58	55.35	12.05
12.0	100.0	9			12.8	
12.0	100.0	9			10.1	
12.0	100.0	9			2.3	
12.0	100.0	9			34.0	
12.0	100.0	9			22.5	
12.0	100.0	9			45.3	
12.0	100.0	9			33.0	
12.0	100.0	9			-2.7	

12.0	100.0	9			4.3	
0.0	50.0	15	33.92	4.03	172.03	3.20
0.0	50.0	15			17.8	
0.0	50.0	15			19.6	
0.0	50.0	15			16.2	
0.0	50.0	15			16.4	
0.0	50.0	15			15.0	
0.0	50.0	15			13.7	
0.0	50.0	15			15.5	
0.0	50.0	15			16.1	
0.0	50.0	15			-23.8	
0.0	50.0	15			-26.4	
0.0	50.0	15			1.8	
12.0	50.0	19	38.90	4.53	-	9.83
12.0	50.0	19			15.1	
12.0	50.0	19			16.4	
12.0	50.0	19			13.3	
12.0	50.0	19			12.4	
12.0	50.0	19			22.1	
12.0	50.0	19			19.1	
12.0	50.0	19			31.0	
12.0	50.0	19			151.5	
12.0	50.0	19			-106.3	
12.0	50.0	19			28.8	
12.0	50.0	19			42.9	
12.0	100.0	21	16.35	5.11	20.90	8.75
12.0	100.0	21			7.4	
12.0	100.0	21			9.7	
12.0	100.0	21			9.9	
12.0	100.0	21			24.1	
12.0	100.0	21			14.8	
0.0	100.0	22	21.51	7.79	22.55	8.03
0.0	100.0	22			617.3	
0.0	100.0	22			17.9	
0.0	100.0	22			11.4	
0.0	100.0	22			9.1	
0.0	100.0	22			7.9	
0.0	100.0	22			7.8	
0.0	100.0	22			-8.4	
12.0	100.0	23	18.11	2.17	20.51	16.39
12.0	100.0	23			27.5	
12.0	100.0	23			24.9	

12.0	100.0	23			17.1	
12.0	100.0	23			21.3	
12.0	100.0	23			3.6	
12.0	100.0	23			8.0	
12.0	100.0	23			4.5	
12.0	100.0	23			12.3	
12.0	100.0	23			19.8	
12.0	100.0	23			151.9	
12.0	100.0	23			111.3	
0.0	100.0	25	84.39	6.91	25.44	53.54
0.0	100.0	25			16.1	
0.0	100.0	25			14.7	
0.0	100.0	25			10.6	
0.0	100.0	25			13.0	
0.0	100.0	25			21.4	
0.0	100.0	25			14.6	
0.0	100.0	25			13.8	
0.0	100.0	25			16.6	
0.0	100.0	25			1182.8	
0.0	100.0	25			242.2	
0.0	100.0	25			45.2	
0.0	100.0	25			290.1	
0.0	100.0	25			118.5	
12.0	50.0	28	85.06	15.37	-	8.24
12.0	50.0	28			-437.1	
12.0	50.0	28			10.0	
12.0	50.0	28			11.5	
12.0	50.0	28			18.5	
12.0	50.0	28			16.1	
12.0	50.0	28			14.3	
12.0	50.0	28			33.4	
12.0	50.0	28			35.7	
0.0	50.0	30	32.81	4.75	20.83	33.48
0.0	50.0	30			12.7	
0.0	50.0	30			44.3	
0.0	50.0	30			14.7	
0.0	50.0	30			10.3	
0.0	50.0	30			12.8	
0.0	50.0	30			14.0	
0.0	50.0	30			31.4	
0.0	50.0	30			47.8	
0.0	50.0	30			22.1	

0.0	50.0	30			-9.2	
0.0	50.0	30			396.8	
0.0	50.0	30			8.7	
0.0	50.0	30			88.8	
0.0	50.0	34	46.20	5.63	37.77	8.11
0.0	50.0	34			30.4	
0.0	50.0	34			22.0	
0.0	50.0	34			17.3	
0.0	50.0	34			15.8	
0.0	50.0	34			11.1	
0.0	50.0	34			11.8	
0.0	50.0	34			14.7	
0.0	50.0	34			61.3	
0.0	50.0	34			-2445.6	
0.0	50.0	34			-18.0	
0.0	50.0	34			1.9	

Data table for chapter 1, Table 1.6

Biochar (t/ha)	Fertilizer (%)	Plot number	N derived from fertilizer sum of flux (kg/ha)	N derived from fertilizer flow weighted average (mg/l)	Leached Water (mm)
0.0	100.0	3	0.5308	0.0003953	262.31
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
0.0	100.0	3			
12.0	50.0	5	0.0001	0.0000001	42.82
12.0	50.0	5			
12.0	50.0	5			
12.0	50.0	5			
12.0	50.0	5			
12.0	50.0	5			
12.0	50.0	5			
12.0	50.0	5			
12.0	50.0	5			
12.0	50.0	5			
12.0	50.0	5			
12.0	50.0	5			
12.0	100.0	9	0.0808	0.0001388	41.67
12.0	100.0	9			
12.0	100.0	9			
12.0	100.0	9			
12.0	100.0	9			
12.0	100.0	9			
12.0	100.0	9			
12.0	100.0	9			
12.0	100.0	9			
12.0	100.0	9			

12.0	100.0	9			
12.0	100.0	9			
12.0	100.0	9			
0.0	50.0	15	0.0045	0.0000053	33.14
0.0	50.0	15			
0.0	50.0	15			
0.0	50.0	15			
0.0	50.0	15			
0.0	50.0	15			
0.0	50.0	15			
0.0	50.0	15			
0.0	50.0	15			
0.0	50.0	15			
0.0	50.0	15			
0.0	50.0	15			
0.0	50.0	15			
12.0	50.0	19	0.1528	0.0001686	12.43
12.0	50.0	19			
12.0	50.0	19			
12.0	50.0	19			
12.0	50.0	19			
12.0	50.0	19			
12.0	50.0	19			
12.0	50.0	19			
12.0	50.0	19			
12.0	50.0	19			
12.0	50.0	19			
12.0	50.0	19			
12.0	50.0	19			
12.0	100.0	21	0.0175	0.0000418	0.20
12.0	100.0	21			
12.0	100.0	21			
12.0	100.0	21			
12.0	100.0	21			
12.0	100.0	21			
12.0	100.0	21			
12.0	100.0	21			
12.0	100.0	21			
12.0	100.0	21			
12.0	100.0	21			
12.0	100.0	21			
0.0	100.0	22	0.0360	0.0001305	21.17

0.0	100.0	22			
0.0	100.0	22			
0.0	100.0	22			
0.0	100.0	22			
0.0	100.0	22			
0.0	100.0	22			
0.0	100.0	22			
0.0	100.0	22			
0.0	100.0	22			
0.0	100.0	22			
0.0	100.0	22			
12.0	100.0	23	0.0661	0.0000794	27.86
12.0	100.0	23			
12.0	100.0	23			
12.0	100.0	23			
12.0	100.0	23			
12.0	100.0	23			
12.0	100.0	23			
12.0	100.0	23			
12.0	100.0	23			
12.0	100.0	23			
12.0	100.0	23			
12.0	100.0	23			
0.0	100.0	25	0.3082	0.0002523	474.95
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
0.0	100.0	25			
12.0	50.0	28	0.0067	0.0000121	6.97
12.0	50.0	28			
12.0	50.0	28			
12.0	50.0	28			
12.0	50.0	28			

12.0	50.0	28			
12.0	50.0	28			
12.0	50.0	28			
12.0	50.0	28			
12.0	50.0	28			
12.0	50.0	28			
12.0	50.0	28			
0.0	50.0	30	0.0147	0.0000213	8.05
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	30			
0.0	50.0	34	0.0017	0.0000017	23.91
0.0	50.0	34			
0.0	50.0	34			
0.0	50.0	34			
0.0	50.0	34			
0.0	50.0	34			
0.0	50.0	34			
0.0	50.0	34			
0.0	50.0	34			
0.0	50.0	34			
0.0	50.0	34			
0.0	50.0	34			
0.0	50.0	34			

Data table from chapter 1, Figure 1.3

Sample date	Plot number	Biochar (t/ha)	Fertilizer (%)	Discharge (L)	NO_3 & NO_2 (mg/l)	NO_3 & NO_2 (mg)
4-Jun	3	0.0	100.0	2.61	2.61	6.79
10-Jun	3	0.0	100.0	2.57	6.67	17.11
12-Jun	3	0.0	100.0	2.92	9.10	26.56
19-Jun	3	0.0	100.0	5.00	6.03	30.15
23-Jun	3	0.0	100.0	3.65	3.11	11.33
2-Jul	3	0.0	100.0	4.61	15.95	73.58
4-Jul	3	0.0	100.0	3.12	18.36	57.34
7-Jul	3	0.0	100.0	2.77	10.24	28.34
15-Jul	3	0.0	100.0	0.93	6.71	6.21
1-Aug	3	0.0	100.0	2.56	0.22	0.56
12-Aug	3	0.0	100.0	2.58	0.00	0.00
29-Aug	3	0.0	100.0	2.63	4.60	12.08
13-Sep	3	0.0	100.0	2.61	4.33	11.28
17-Oct	3	0.0	100.0	3.04	2.71	8.23
4-Jun	5	12.0	50.0	2.69	6.56	17.66
10-Jun	5	12.0	50.0	0.57	77.34	44.28
12-Jun	5	12.0	50.0	4.69	3.01	14.12
19-Jun	5	12.0	50.0	10.28	1.96	20.19
23-Jun	5	12.0	50.0	3.78	38.20	144.54
2-Jul	5	12.0	50.0	4.63	11.97	55.39
4-Jul	5	12.0	50.0	0.39	6.75	2.61
7-Jul	5	12.0	50.0	0.26	6.61	1.72
15-Jul	5	12.0	50.0	0.04	3.96	0.15
1-Aug	5	12.0	50.0	0.19	5.65	1.10
12-Aug	5	12.0	50.0	0.22	1.28	0.28
13-Sep	5	12.0	50.0	0.09	1.66	0.15
4-Jun	9	12.0	100.0	0.07	0.65	0.04
19-Jun	9	12.0	100.0	4.23	4.51	19.05
23-Jun	9	12.0	100.0	2.56	6.46	16.51
2-Jul	9	12.0	100.0	2.57	13.19	33.88
4-Jul	9	12.0	100.0	0.01	0.00	0.00
7-Jul	9	12.0	100.0	0.00	0.00	0.00
1-Aug	9	12.0	100.0	2.55	1.70	4.33
12-Aug	9	12.0	100.0	2.61	0.00	0.00
13-Sep	9	12.0	100.0	0.81	0.84	0.68
17-Oct	9	12.0	100.0	2.61	0.00	0.00
4-Jun	15	0.0	50.0	0.97	3.97	3.85
10-Jun	15	0.0	50.0	1.40	2.47	3.46

12-Jun	15	0.0	50.0	0.11	21.43	2.37
19-Jun	15	0.0	50.0	3.63	6.65	24.13
23-Jun	15	0.0	50.0	3.19	4.45	14.21
2-Jul	15	0.0	50.0	3.85	5.77	22.20
4-Jul	15	0.0	50.0	3.00	0.00	0.00
7-Jul	15	0.0	50.0	2.73	6.42	17.49
15-Jul	15	0.0	50.0	1.90	8.34	15.88
1-Aug	15	0.0	50.0	1.91	0.00	0.00
12-Aug	15	0.0	50.0	2.61	0.00	0.00
13-Sep	15	0.0	50.0	2.00	0.00	0.00
17-Oct	15	0.0	50.0	3.12	0.00	0.00
4-Jun	19	12.0	50.0	1.44	5.30	7.65
10-Jun	19	12.0	50.0	0.02	2.95	0.05
12-Jun	19	12.0	50.0	3.48	35.15	122.35
23-Jun	19	12.0	50.0	3.03	4.94	14.95
2-Jul	19	12.0	50.0	4.27	7.49	31.96
4-Jul	19	12.0	50.0	2.87	5.09	14.60
7-Jul	19	12.0	50.0	2.61	9.53	24.86
15-Jul	19	12.0	50.0	0.04	0.04	0.00
1-Aug	19	12.0	50.0	2.59	6.57	17.05
12-Aug	19	12.0	50.0	2.61	7.61	19.84
13-Sep	19	12.0	50.0	1.73	0.00	0.00
17-Oct	19	12.0	50.0	3.37	0.11	0.36
4-Jun	21	12.0	100.0	4.43	7.47	33.13
19-Jun	21	12.0	100.0	3.04	0.00	0.00
23-Jun	21	12.0	100.0	2.61	2.81	7.32
2-Jul	21	12.0	100.0	0.19	4.30	0.80
4-Jul	21	12.0	100.0	0.01	0.00	0.00
12-Aug	21	12.0	100.0	0.06	1.57	0.10
17-Oct	21	12.0	100.0	2.61	1.06	2.78
4-Jun	22	0.0	100.0	1.67	8.44	14.07
10-Jun	22	0.0	100.0	0.04	2.82	0.11
19-Jun	22	0.0	100.0	3.32	0.00	0.00
23-Jun	22	0.0	100.0	2.76	2.64	7.29
2-Jul	22	0.0	100.0	0.37	4.37	1.64
4-Jul	22	0.0	100.0	0.11	3.36	0.36
7-Jul	22	0.0	100.0	0.08	0.00	0.00
17-Oct	22	0.0	100.0	0.20	0.00	0.00
3-Jun	23	12.0	100.0	2.63	6.88	18.12
10-Jun	23	12.0	100.0	0.09	5.86	0.52
12-Jun	23	12.0	100.0	1.31	3.20	4.18
19-Jun	23	12.0	100.0	10.12	0.78	7.90

23-Jun	23	12.0	100.0	3.40	0.00	0.00
2-Jul	23	12.0	100.0	3.82	0.00	0.00
4-Jul	23	12.0	100.0	0.27	0.00	0.00
7-Jul	23	12.0	100.0	0.15	1.38	0.21
15-Jul	23	12.0	100.0	0.10	6.40	0.64
1-Aug	23	12.0	100.0	0.06	10.59	0.66
12-Aug	23	12.0	100.0	0.17	0.00	0.00
17-Oct	23	12.0	100.0	3.67	0.14	0.51
4-Jun	25	0.0	100.0	2.81	8.61	24.18
10-Jun	25	0.0	100.0	2.60	6.58	17.12
12-Jun	25	0.0	100.0	3.00	81.71	245.18
19-Jun	25	0.0	100.0	4.23	4.32	18.26
23-Jun	25	0.0	100.0	3.18	2.88	9.18
2-Jul	25	0.0	100.0	3.31	8.33	27.53
4-Jul	25	0.0	100.0	2.93	4.32	12.63
7-Jul	25	0.0	100.0	2.85	6.71	19.16
15-Jul	25	0.0	100.0	1.74	7.45	12.96
1-Aug	25	0.0	100.0	2.57	2.51	6.45
12-Aug	25	0.0	100.0	2.59	0.06	0.15
29-Aug	25	0.0	100.0	0.16	0.00	0.00
13-Sep	25	0.0	100.0	2.58	0.00	0.00
17-Oct	25	0.0	100.0	3.27	0.00	0.00
4-Jun	28	12.0	50.0	0.07	0.02	0.00
12-Jun	28	12.0	50.0	0.19	1.87	0.35
19-Jun	28	12.0	50.0	3.54	1.99	7.06
23-Jun	28	12.0	50.0	3.01	4.92	14.80
2-Jul	28	12.0	50.0	3.23	5.82	18.78
4-Jul	28	12.0	50.0	2.86	0.38	1.09
7-Jul	28	12.0	50.0	1.03	3.02	3.12
15-Jul	28	12.0	50.0	0.02	0.00	0.00
17-Oct	28	12.0	50.0	3.26	0.00	0.00
4-Jun	30	0.0	50.0	2.51	8.07	20.23
10-Jun	30	0.0	50.0	0.05	2.24	0.12
12-Jun	30	0.0	50.0	0.05	2.31	0.13
19-Jun	30	0.0	50.0	3.04	1.88	5.72
23-Jun	30	0.0	50.0	3.45	4.26	14.68
2-Jul	30	0.0	50.0	4.17	6.50	27.13
4-Jul	30	0.0	50.0	3.12	6.17	19.26
7-Jul	30	0.0	50.0	0.18	3.69	0.68
15-Jul	30	0.0	50.0	0.10	6.84	0.70
1-Aug	30	0.0	50.0	0.19	0.03	0.00
12-Aug	30	0.0	50.0	0.40	0.00	0.00

29-Aug	30	0.0	50.0	0.17	0.00	0.00
13-Sep	30	0.0	50.0	2.64	0.00	0.00
17-Oct	30	0.0	50.0	1.31	0.00	0.00
4-Jun	34	0.0	50.0	1.00	2.93	2.93
10-Jun	34	0.0	50.0	1.79	0.00	0.00
12-Jun	34	0.0	50.0	0.90	4.28	3.85
19-Jun	34	0.0	50.0	4.70	6.81	32.00
23-Jun	34	0.0	50.0	3.11	3.02	9.40
2-Jul	34	0.0	50.0	3.61	5.98	21.60
4-Jul	34	0.0	50.0	3.06	3.87	11.84
7-Jul	34	0.0	50.0	2.87	0.00	0.00
15-Jul	34	0.0	50.0	2.61	0.53	1.37
1-Aug	34	0.0	50.0	2.60	7.54	19.64
12-Aug	34	0.0	50.0	2.64	0.00	0.00
13-Sep	34	0.0	50.0	2.64	0.00	0.00
17-Oct	34	0.0	50.0	0.13	0.46	0.06

Data table from chapter 1, Figure 1.4

Plot number	Biochar (t/ha)	Fertilizer (%)	Leaching N derived from fertilizer (kg/ha)	Leaching N derived from fertilizer (%)	Plant biomass N derived from fertilizer (kg/ha)	Plant biomass N derived from fertilizer (%)
3	0	100	0.5308	0.442	61.73	51.46
5	12	50	0.0001	0.000	24.65	37.26
9	12	100	0.0808	0.067	68.54	57.14
15	0	50	0.0045	0.007	21.34	32.26
19	12	50	0.1528	0.231	16.80	25.40
21	12	100	0.0175	0.015	60.61	50.53
22	0	100	-	-	45.13	37.62
23	12	100	0.0661	0.055	52.03	43.37
25	0	100	0.3082	0.257	57.91	48.27
28	12	50	0.0067	0.010	25.50	38.54
30	0	50	0.0147	0.022	22.37	33.82
34	0	50	0.0017	0.003	13.65	20.63

Data from chapter 1, Figure 1.4

Plot number	Biochar (t/ha)	Fertilizer (%)	Soil N derived from fertilizer (kg/ha)	Soil N derived from fertilizer (%)	Microbial biomass N derived from fertilizer (kg/ha)	Microbial biomass N derived from fertilizer (%)
3	0	100	20.48795352	17.0789876	0.000636591	0.063659143
5	12	50	15.03147569	22.71988466	0.00048974	0.048973983
9	12	100	50.02535061	41.70169274	0.003275006	0.327500591
15	0	50	13.43412132	20.30550381	0.000620493	0.062049322
19	12	50	11.44923799	17.30537786	3.13937E-05	0.003139372
21	12	100	28.13345862	23.45236631	0.00531447	0.531446999
22	0	100	9.037418319	7.533693164	0.001541144	0.154114447
23	12	100	40.26099488	33.56201641	0.000348929	0.034892921
25	0	100	23.77832546	19.82187851	0.000515626	0.051562617
28	12	50	47.24871005	71.41582534	0.002815677	0.281567746
30	0	50	14.40932455	21.7795111	0.001211805	0.121180522
34	0	50	45.05402468	68.09858627	0.003562837	0.356283705

Data table from chapter 1, Table 1.4

Plot number	Biochar (t/ha)	Fertilizer (%)	Total N derived from fertilizer (kg/ha)	Total N derived from fertilizer (%)
3	0	100	82.74719054	69.04211358
5	12	50	39.68221024	60.03302314
9	12	100	118.6538209	99.23592499
15	0	50	34.77773995	52.63210058
19	12	50	28.40148831	42.93545439
21	12	100	88.77021245	74.52686046
22	0	100	54.16484894	45.30525466
23	12	100	92.35279732	77.02092859
25	0	100	81.99682996	68.40460891
28	12	50	72.75340769	110.2489909
30	0	50	36.79465492	55.73911728
34	0	50	58.70559878	89.0867842

Data table for chapter 2, Figure 2.1; Figure 2.2; Figure 2.3; Figure 2.4

Conversion year	Years since conversion	Treatment	Fertilizer	Stover yield (t/ha)	Grain yield (t/ha)	Year
1973	37	Sawdust	+	6.16	3.77	2010
1973	37	Charcoal	+	4.91	4.32	2010
1973	37	Tithonia	+	6.08	3.62	2010
1973	37	Sawdust	-	5.37	3.78	2010
1973	37	Charcoal	-	5.31	2.86	2010
1973	37	Tithonia	-	3.03	2.48	2010
1973	37	Contol	-	4.18	2.74	2010
1973	37	Control	+	5.62	4.26	2010
1973	37	Farmer Practice	+	7.32	5.22	2010
1973	37	Sawdust	+	4.70	3.43	2010
1973	37	Charcoal	+	2.59	10.12	2010
1973	37	Tithonia	+	7.21	6.02	2010
1973	37	Sawdust	-	1.54	0.31	2010
1973	37	Charcoal	-	1.01	-	2010
1973	37	Tithonia	-	0.59	0.34	2010
1973	37	Contol	-	1.29	0.92	2010
1973	37	Control	+	5.24	4.16	2010
1973	37	Farmer Practice	+	2.98	2.23	2010
1900	110	Sawdust	+	8.36	5.52	2010
1900	110	Charcoal	+	4.83	3.26	2010
1900	110	Tithonia	+	7.24	4.40	2010
1900	110	Sawdust	-	6.95	4.09	2010
1900	110	Charcoal	-	5.12	3.38	2010
1900	110	Tithonia	-	6.59	3.90	2010
1900	110	Contol	-	1.78	1.18	2010
1900	110	Control	+	2.10	3.77	2010
1900	110	Farmer Practice	+	1.50	2.27	2010
1900	110	Sawdust	+	5.27	3.80	2010
1900	110	Charcoal	+	8.07	4.92	2010
1900	110	Tithonia	+	7.06	3.81	2010
1900	110	Sawdust	-	2.51	1.33	2010
1900	110	Charcoal	-	2.96	1.58	2010
1900	110	Tithonia	-	1.02	0.76	2010
1900	110	Contol	-	0.26	0.18	2010
1900	110	Control	+	6.09	3.70	2010
1900	110	Farmer Practice	+	3.66	3.05	2010
1900	110	Sawdust	+	4.52	3.81	2010
1900	110	Charcoal	+	2.07	2.03	2010

1900	110	Tithonia	+	2.32	2.18	2010
1900	110	Sawdust	-	1.41	1.14	2010
1900	110	Charcoal	-	1.26	1.67	2010
1900	110	Tithonia	-	2.50	1.77	2010
1900	110	Contol	-	1.76	1.02	2010
1900	110	Control	+	5.83	6.43	2010
1900	110	Farmer Practice	+			2010
1930	80	Sawdust	+	7.60	4.39	2010
1930	80	Charcoal	+	8.00	7.21	2010
1930	80	Tithonia	+	7.13	4.70	2010
1930	80	Sawdust	-	3.14	1.51	2010
1930	80	Charcoal	-	1.11	1.63	2010
1930	80	Tithonia	-	1.89	1.16	2010
1930	80	Contol	-	3.96	2.49	2010
1930	80	Control	+	8.46	7.00	2010
1930	80	Farmer Practice	+	4.91	5.04	2010
1922	88	Sawdust	+	4.88	5.08	2010
1922	88	Charcoal	+	3.43	2.82	2010
1922	88	Tithonia	+	5.43	2.03	2010
1922	88	Sawdust	-	3.62	3.81	2010
1922	88	Charcoal	-	3.66	2.83	2010
1922	88	Tithonia	-	3.04	3.70	2010
1922	88	Contol	-	2.79	2.54	2010
1922	88	Control	+	4.24	1.96	2010
1922	88	Farmer Practice	+	-	-	2010
1921	89	Sawdust	+	5.64	4.65	2010
1921	89	Charcoal	+	4.41	4.35	2010
1921	89	Tithonia	+	4.94	4.05	2010
1921	89	Sawdust	-	2.37	2.18	2010
1921	89	Charcoal	-	3.18	2.70	2010
1921	89	Tithonia	-	2.27	2.24	2010
1921	89	Contol	-	4.83	4.65	2010
1921	89	Control	+	8.90	7.88	2010
1921	89	Farmer Practice	+	-	-	2010
1986	24	Sawdust	+	5.09	5.55	2010
1986	24	Charcoal	+	4.30	5.42	2010
1986	24	Tithonia	+	2.80	2.64	2010
1986	24	Sawdust	-	5.60	3.40	2010
1986	24	Charcoal	-	3.47	4.40	2010
1986	24	Tithonia	-	3.78	4.29	2010
1986	24	Contol	-	3.04	4.07	2010
1986	24	Control	+	3.75	4.14	2010

1986	24	Farmer Practice	+	4.28	5.23	2010
1986	24	Sawdust	+	5.05	4.82	2010
1986	24	Charcoal	+	4.11	4.07	2010
1986	24	Tithonia	+	5.03	4.77	2010
1986	24	Sawdust	-	2.38	0.51	2010
1986	24	Charcoal	-	1.38	1.59	2010
1986	24	Tithonia	-	2.78	2.23	2010
1986	24	Contol	-	1.38	1.36	2010
1986	24	Control	+	2.88	2.40	2010
1986	24	Farmer Practice	+	3.57	2.39	2010
1986	24	Sawdust	+	5.28	3.93	2010
1986	24	Charcoal	+	5.11	4.37	2010
1986	24	Tithonia	+	5.06	5.01	2010
1986	24	Sawdust	-	2.18	2.75	2010
1986	24	Charcoal	-	1.73	1.41	2010
1986	24	Tithonia	-	3.11	2.06	2010
1986	24	Contol	-	1.47	1.66	2010
1986	24	Control	+	3.24	1.24	2010
1986	24	Farmer Practice	+	1.42	1.31	2010
2002	8	Sawdust	+	5.79	6.16	2010
2002	8	Charcoal	+	6.00	6.01	2010
2002	8	Tithonia	+	4.66	5.50	2010
2002	8	Sawdust	-	2.95	3.65	2010
2002	8	Charcoal	-	4.33	5.76	2010
2002	8	Tithonia	-	4.48	4.16	2010
2002	8	Contol	-	5.27	5.66	2010
2002	8	Control	+	5.28	5.73	2010
2002	8	Farmer Practice	+	3.94	5.51	2010
2002	8	Sawdust	+	5.70	7.28	2010
2002	8	Charcoal	+	4.95	6.01	2010
2002	8	Tithonia	+	3.85	5.59	2010
2002	8	Sawdust	-	5.29	7.13	2010
2002	8	Charcoal	-	5.13	5.92	2010
2002	8	Tithonia	-	6.66	6.23	2010
2002	8	Contol	-	3.83	5.03	2010
2002	8	Control	+	7.87	6.57	2010
2002	8	Farmer Practice	+	3.27	5.99	2010
1996	14	Sawdust	+	2.31	2.54	2010
1996	14	Charcoal	+	3.80	3.57	2010
1996	14	Tithonia	+	3.45	3.93	2010
1996	14	Sawdust	-	1.50	2.55	2010
1996	14	Charcoal	-	1.81	2.34	2010

1996	14	Tithonia	-	0.95	3.22	2010
1996	14	Contol	-	2.63	1.02	2010
1996	14	Control	+	2.62	3.97	2010
1996	14	Farmer Practice	+	-	2.24	2010
1996	14	Sawdust	+	3.15	4.34	2010
1996	14	Charcoal	+	4.74	4.30	2010
1996	14	Tithonia	+	6.98	4.94	2010
1996	14	Sawdust	-	3.68	3.18	2010
1996	14	Charcoal	-	6.72	5.19	2010
1996	14	Tithonia	-	4.46	3.99	2010
1996	14	Contol	-	6.11	6.36	2010
1996	14	Control	+	5.26	4.90	2010
1996	14	Farmer Practice	+	5.33	7.18	2010
1997	13	Sawdust	+	4.82	6.66	2010
1997	13	Charcoal	+	2.72	3.50	2010
1997	13	Tithonia	+	5.73	4.93	2010
1997	13	Sawdust	-	5.48	3.88	2010
1997	13	Charcoal	-	3.47	3.39	2010
1997	13	Tithonia	-	8.71	5.29	2010
1997	13	Contol	-	2.72	0.58	2010
1997	13	Control	+	1.45	1.43	2010
1997	13	Farmer Practice	+	5.10	4.38	2010
2000	10	Sawdust	+	3.93	4.80	2010
2000	10	Charcoal	+	3.18	4.35	2010
2000	10	Tithonia	+	3.69	4.84	2010
2000	10	Sawdust	-	3.97	4.93	2010
2000	10	Charcoal	-	5.98	4.60	2010
2000	10	Tithonia	-	3.09	2.23	2010
2000	10	Contol	-	5.07	4.14	2010
2000	10	Control	+	4.73	4.66	2010
2000	10	Farmer Practice	+	4.42	4.07	2010
2001	9	Sawdust	+	5.68	4.01	2010
2001	9	Charcoal	+	4.76	3.64	2010
2001	9	Tithonia	+	4.69	3.61	2010
2001	9	Sawdust	-	2.75	2.50	2010
2001	9	Charcoal	-	5.27	3.51	2010
2001	9	Tithonia	-	2.62	3.27	2010
2001	9	Contol	-	3.20	2.10	2010
2001	9	Control	+	3.37	3.41	2010
2001	9	Farmer Practice	+	4.91	5.05	2010
2000	10	Sawdust	+	4.84	3.68	2010
2000	10	Charcoal	+	5.01	4.03	2010

2000	10	Tithonia	+	4.47	3.98	2010
2000	10	Sawdust	-	3.34	4.45	2010
2000	10	Charcoal	-	2.94	3.78	2010
2000	10	Tithonia	-	2.56	2.59	2010
2000	10	Contol	-	5.14	4.51	2010
2000	10	Control	+	4.99	4.40	2010
2000	10	Farmer Practice	+	4.02	5.54	2010
1950	60	Sawdust	+	4.09	2.80	2010
1950	60	Charcoal	+	4.20	2.87	2010
1950	60	Tithonia	+	3.32	2.28	2010
1950	60	Sawdust	-	2.33	1.40	2010
1950	60	Charcoal	-	0.69	0.18	2010
1950	60	Tithonia	-	1.64	1.13	2010
1950	60	Contol	-	-		2010
1950	60	Control	+	2.46	1.47	2010
1950	60	Farmer Practice	+	-	-	2010
1950	60	Sawdust	+	5.98	4.41	2010
1950	60	Charcoal	+	5.30	3.05	2010
1950	60	Tithonia	+	4.19	2.95	2010
1950	60	Sawdust	-	7.50	3.91	2010
1950	60	Charcoal	-	5.79	3.03	2010
1950	60	Tithonia	-	4.74	3.06	2010
1950	60	Contol	-	2.10	1.35	2010
1950	60	Control	+	3.75	4.21	2010
1950	60	Farmer Practice	+	4.51	3.68	2010
1973	36	Tithonia	+	2.67	0.60	2009
1973	36	Biochar	+	4.92	1.24	2009
1973	36	Sawdust	+	2.54	0.38	2009
1973	36	Tithonia	-	1.14	0.19	2009
1973	36	Biochar	-	2.98	0.26	2009
1973	36	Sawdust	-	3.34	1.58	2009
1973	36	Farmer Practices	+	11.97	6.50	2009
1900	109	Tithonia	+	8.78	4.47	2009
1900	109	Biochar	+	9.53	1.95	2009
1900	109	Sawdust	+	6.63	4.35	2009
1900	109	Control	+	2.83	1.54	2009
1900	109	Tithonia	-	2.87	2.85	2009
1900	109	Biochar	-	6.28	5.90	2009
1900	109	Sawdust	-	3.95	2.53	2009
1900	109	Control	-	1.14		2009
1900	109	Farmer	+	7.03	3.59	2009

		Practices				
1986	23	Tithonia	+	5.15	4.25	2009
1986	23	Biochar	+	4.68	3.77	2009
1986	23	Sawdust	+	5.74	2.36	2009
1986	23	Control	+	2.19	1.47	2009
1986	23	Biochar	-	2.84	2.63	2009
1986	23	Sawdust	-	3.30	4.26	2009
1986	23	Control	-	3.04	0.94	2009
1986	23	Farmer Practices	+	-	-	2009
2002	7	Tithonia	+	15.64	11.96	2009
2002	7	Biochar	+	16.69	10.48	2009
2002	7	Sawdust	+	15.84	2.34	2009
2002	7	Control	+	7.59	7.49	2009
2002	7	Tithonia	-	13.74	11.96	2009
2002	7	Biochar	-	10.72	9.42	2009
2002	7	Sawdust	-	13.26	9.33	2009
2002	7	Control	-	14.47	14.48	2009
2002	7	Farmer Practices	+	13.21	13.21	2009
1986	23	Tithonia	+	3.85	26.66	2009
1986	23	Biochar	+	5.12	35.68	2009
1986	23	Sawdust	+	4.34	15.30	2009
1986	23	Control	+	1.26	3.25	2009
1986	23	Tithonia	-	0.54	22.09	2009
1986	23	Sawdust	-	0.46	0.16	2009
1986	23	Control	-	0.23	0.07	2009
1986	23	Farmer Practices	+	6.73	12.11	2009
1996	13	Biochar	+	5.46	3.71	2009
1996	13	Sawdust	+	3.90	3.77	2009
1996	13	Tithonia	-	7.15	6.14	2009
1996	13	Biochar	-	4.52	3.14	2009
1996	13	Sawdust	-	7.41	9.04	2009
1996	13	Farmer Practices	+	8.83	7.38	2009
2002	7	Tithonia	+	4.32	2.95	2009
2002	7	Biochar	+	5.34	9.06	2009
2002	7	Sawdust	+	8.97	5.51	2009
2002	7	Control	+	5.30	3.82	2009
2002	7	Tithonia	-	12.24	7.63	2009
2002	7	Biochar	-	19.75	12.25	2009

2002	7	Sawdust	-	9.17	10.62	2009
2002	7	Control	-	10.42	6.87	2009
2002	7	Farmer Practices	+	6.07	4.80	2009
1900	109	Biochar	+	9.15	3.33	2009
1900	109	Biochar	-	9.12	5.88	2009
1900	109	Sawdust	+	8.23	7.22	2009
1900	109	Sawdust	-	8.84	4.39	2009
1900	109	Tithonia	+	9.28	14.75	2009
1900	109	Tithonia	-	9.82	5.48	2009
1900	109	Control	+	5.12	3.09	2009
1900	109	Control	-	4.22	0.84	2009
1997	12	Biochar	+	11.15	5.74	2009
1997	12	Biochar	-	15.29	8.94	2009
1997	12	Sawdust	+	16.90	8.94	2009
1997	12	Sawdust	-	10.89	6.06	2009
1997	12	Tithonia	+	14.95	7.30	2009
1997	12	Tithonia	-	16.78	4.27	2009
1997	12	Control	+	9.37	4.80	2009
1997	12	Control	-	13.51	7.03	2009
1997	12	Farmer Practices	+	12.83	10.87	2009
1986	23	Biochar	+	11.00	10.05	2009
1986	23	Biochar	-	8.73	6.67	2009
1986	23	Sawdust	+	7.90	5.90	2009
1986	23	Sawdust	-	7.46	4.49	2009
1986	23	Tithonia	+	10.62	6.01	2009
1986	23	Tithonia	-	10.50	7.34	2009
1986	23	Control	+	5.57	3.31	2009
1986	23	Control	-	7.26	2.68	2009
1986	23	Farmer Practices	+	14.21	7.22	2009
1921	88	Biochar	+	6.82	7.29	2009
1921	88	Biochar	-	3.54	2.27	2009
1921	88	Sawdust	+	4.03	3.70	2009
1921	88	Sawdust	-	2.70	1.77	2009
1921	88	Tithonia	+	6.39	6.12	2009
1921	88	Tithonia	-	4.85	1.79	2009
1921	88	Control	+	2.99	2.39	2009
1921	88	Control	-	2.64	34.93	2009
1921	88	Farmer Practices	+	5.91	1.48	2009

2000	9	Biochar	+	6.40	3.20	2009
2000	9	Biochar	-	6.28	3.89	2009
2000	9	Sawdust	+	4.74	3.13	2009
2000	9	Sawdust	-	6.52	6.18	2009
2000	9	Tithonia	+	9.25	4.50	2009
2000	9	Tithonia	-	3.31	1.71	2009
2000	9	Control	+	3.18	1.69	2009
2000	9	Control	-	7.66	6.12	2009
2000	9	Farmer Practices	+	15.54	6.10	2009
1900	109	Biochar	+	8.68	3.65	2009
1900	109	Biochar	-	6.19	3.47	2009
1900	109	Sawdust	+	6.21	5.01	2009
1900	109	Sawdust	-	3.77	2.31	2009
1900	109	Tithonia	+	8.23	4.80	2009
1900	109	Tithonia	-	5.05	2.33	2009
1900	109	Control	+	3.07	0.56	2009
1900	109	Control	-	3.35	1.45	2009
1900	109	Farmer Practices	+	3.32	4.84	2009
1922	87	Biochar	+	7.12	6.33	2009
1922	87	Biochar	-	4.29	4.56	2009
1922	87	Sawdust	+	3.91	4.37	2009
1922	87	Sawdust	-	5.76	6.60	2009
1922	87	Tithonia	+	3.64	3.00	2009
1922	87	Tithonia	-	5.92	5.47	2009
1922	87	Control	+	5.96	2.70	2009
1922	87	Control	-	6.83	3.07	2009
1922	87	Farmer Practices	+	5.30	2.13	2009
2002	7	Biochar	+	9.97	10.40	2009
2002	7	Biochar	-	9.96	9.25	2009
2002	7	Sawdust	+	19.93	14.55	2009
2002	7	Sawdust	-	14.69	15.66	2009
2002	7	Tithonia	+	15.04	14.44	2009
2002	7	Tithonia	-	13.38	10.57	2009
2002	7	Control	+	4.18	4.57	2009
2002	7	Control	-	13.48	13.39	2009
2002	7	Farmer Practices	+	16.34	11.29	2009
1973	36	Biochar	+	34.43	8.15	2009
1973	36	Biochar	-	8.35	2.90	2009

1973	36	Sawdust	+	27.07	7.18	2009
1973	36	Sawdust	-	15.35	4.98	2009
1973	36	Tithonia	+	20.99	7.75	2009
1973	36	Tithonia	-	15.53	4.51	2009
1973	36	Control	+	9.16	2.02	2009
1973	36	Control	-	4.51	0.67	2009
2001	8	Biochar	+	3.24	4.73	2009
2001	8	Biochar	-	2.34	0.56	2009
2001	8	Sawdust	+	6.69	2.38	2009
2001	8	Sawdust	-	4.68	1.90	2009
2001	8	Tithonia	+	6.49	4.90	2009
2001	8	Tithonia	-	10.60	1.10	2009
2001	8	Control	+	4.35	2.47	2009
2001	8	Control	-	4.83	4.36	2009
2001	8	Farmer Practices	+	11.45	9.08	2009
2000	9	Biochar	+	5.46	2.43	2009
2000	9	Biochar	-	4.52	2.27	2009
2000	9	Sawdust	+	3.90	2.51	2009
2000	9	Sawdust	-	7.41	5.96	2009
2000	9	Tithonia	+	3.87	2.09	2009
2000	9	Tithonia	-	7.15	3.97	2009
2000	9	Farmer Practices	+	8.83	7.38	2009
1950	59	Biochar	+	6.64	5.96	2009
1950	59	Sawdust	+	5.60	3.49	2009
1950	59	Sawdust	-	6.04	3.77	2009
1950	59	Tithonia	+	4.74	4.02	2009
1950	59	Tithonia	-	2.98	1.74	2009
1950	59	Control	+	3.03	1.77	2009
1950	59	Control	-	6.29	3.90	2009
1950	59	Farmer Practices	+	4.70	3.36	2009
1950	59	Biochar	+	5.47	8.05	2009
1950	59	Biochar	-	6.61	7.59	2009
1950	59	Sawdust	+	7.31	5.34	2009
1950	59	Sawdust	-	6.52	4.57	2009
1950	59	Tithonia	+	9.43	6.06	2009
1950	59	Tithonia	-	9.15	4.76	2009
1950	59	Control	+	2.85	1.89	2009
1950	59	Control	-	3.88	2.56	2009
1950	59	Farmer	+	21.56	15.02	2009

		Practices				
1950	59	Biochar	+	10.79	6.69	2009
1950	59	Biochar	-	3.70	0.69	2009
1950	59	Sawdust	+	7.71	3.93	2009
1950	59	Sawdust	-	5.58	1.56	2009
1950	59	Tithonia	+	7.45	5.62	2009
1950	59	Tithonia	-	3.63	1.06	2009
1950	59	Control	+	4.78	3.16	2009
1950	59	Control	-	5.18	4.43	2009
1950	59	Farmer Practices	+	8.46	5.00	2009
1900	108	Tithonia	+	35.09	5.37	2008
1900	108	Charcoal	+	25.26	3.63	2008
1900	108	Sawdust	+	26.84	4.10	2008
1900	108	Tithonia	-	65.01	7.00	2008
1900	108	Charcoal	-	46.95	3.72	2008
1900	108	Sawdust	-	55.77	2.57	2008
1900	108	Control	+	29.86	5.07	2008
1900	108	Control	-	15.63	5.62	2008
1900	108	Tithonia	+	11.95	7.25	2008
1900	108	Charcoal	+	6.25	6.14	2008
1900	108	Sawdust	+	7.97	1.48	2008
1900	108	Tithonia	-	4.66	4.78	2008
1900	108	Charcoal	-	6.68	2.09	2008
1900	108	Sawdust	-	7.38	3.34	2008
1900	108	Control	+	6.80	3.90	2008
1900	108	Control	-	2.93	0.96	2008
1922	86	Tithonia	+	8.03	4.13	2008
1922	86	Charcoal	+	2.24	3.48	2008
1922	86	Sawdust	+	6.00	2.00	2008
1922	86	Tithonia	-	5.09	1.72	2008
1922	86	Charcoal	-	6.72	3.42	2008
1922	86	Sawdust	-	7.06	0.18	2008
1922	86	Control	-	4.35	2.67	2008
1921	87	Tithonia	+	11.75	10.95	2008
1921	87	Charcoal	+	10.15	6.34	2008
1921	87	Sawdust	+	7.51	8.71	2008
1921	87	Tithonia	-	3.75	4.31	2008
1921	87	Charcoal	-	4.32	5.12	2008
1921	87	Sawdust	-	5.21	2.87	2008
1921	87	Control	+	4.57	4.41	2008
1921	87	Control	-	2.05	1.67	2008

1930	78	Tithonia	+	21.62	11.17	2008
1930	78	Charcoal	+	13.55	8.20	2008
1930	78	Sawdust	+	5.76	5.49	2008
1930	78	Tithonia	-	6.25	2.60	2008
1930	78	Charcoal	-	2.85	0.67	2008
1930	78	Sawdust	-	3.39	0.76	2008
1930	78	Control	+	10.04	5.39	2008
1930	78	Control	-	8.05	4.95	2008
2001	7	Tithonia	+	10.95	4.42	2008
2001	7	Charcoal	+	11.11	2.16	2008
2001	7	Sawdust	+	8.13	3.11	2008
2001	7	Tithonia	-	13.32	5.99	2008
2001	7	Charcoal	-	16.52	4.24	2008
2001	7	Sawdust	-	18.49	7.43	2008
2001	7	Control	+	19.72	4.94	2008
2001	7	Control	-	5.30	2.52	2008
2000	8	Tithonia	+	11.53	6.30	2008
2000	8	Charcoal	+	7.44	5.99	2008
2000	8	Tithonia	-	13.35	8.07	2008
2000	8	Charcoal	-	13.62	5.18	2008
2000	8	Sawdust	-	10.11	3.94	2008
2000	8	Control	+	23.13	4.79	2008
2000	8	Control	-	3.37	3.06	2008
1950	58	Tithonia	+	21.19	6.48	2008
1950	58	Charcoal	+	13.24	6.58	2008
1950	58	Sawdust	+	13.87	6.41	2008
1950	58	Tithonia	-	13.54	6.30	2008
1950	58	Charcoal	-	15.38	7.82	2008
1950	58	Sawdust	-	15.52	6.37	2008
1950	58	Control	+	13.95	9.57	2008
1950	58	Control	-	10.08	3.67	2008
1950	58	Tithonia	+	8.79	3.82	2008
1950	58	Charcoal	+	14.02	5.54	2008
1950	58	Sawdust	+	12.74	3.80	2008
1950	58	Tithonia	-	7.97	4.25	2008
1950	58	Charcoal	-	7.62	4.90	2008
1950	58	Sawdust	-	9.32	3.72	2008
1950	58	Control	+	12.81	5.43	2008
1950	58	Control	-	7.18	4.42	2008
1950	58	Tithonia	+	2.99	9.42	2008
1950	58	Charcoal	+	3.63	5.55	2008
1950	58	Sawdust	+	3.38	3.36	2008

1950	58	Tithonia	-	8.87	4.62	2008
1950	58	Charcoal	-	4.70	3.19	2008
1950	58	Sawdust	-	6.47	7.97	2008
1950	58	Control	+	6.14	3.07	2008
1997	11	Tithonia	+	6.52	5.81	2008
1997	11	Charcoal	+	7.91	5.47	2008
1997	11	Sawdust	+	8.08	4.75	2008
1997	11	Tithonia	-	19.10	5.30	2008
1997	11	Charcoal	-	17.97	3.11	2008
1997	11	Sawdust	-	12.49	4.46	2008
1997	11	Control	+	20.04	5.15	2008
1997	11	Control	-	12.86	3.27	2008
1996	12	Tithonia	+	10.31	2.94	2008
1996	12	Charcoal	+	5.77	1.20	2008
1996	12	Sawdust	+	12.16	0.90	2008
1996	12	Tithonia	-	10.49	2.16	2008
1996	12	Charcoal	-	9.84	2.98	2008
1996	12	Sawdust	-	10.64	5.45	2008
1996	12	Control	+	10.38	2.90	2008
1996	12	Control	-	11.02	2.56	2008
2002	6	Tithonia	+	9.36	2.89	2008
2002	6	Charcoal	+	3.19	2.23	2008
2002	6	Sawdust	+	2.13	1.60	2008
2002	6	Tithonia	-	5.26	1.42	2008
2002	6	Charcoal	-	6.18	3.31	2008
2002	6	Sawdust	-	7.80	3.70	2008
2002	6	Control	+	6.95	3.78	2008
2002	6	Control	-	3.65	2.82	2008
2002	6	Tithonia	+	11.04	9.38	2008
2002	6	Charcoal	+	8.97	5.38	2008
2002	6	Sawdust	+	18.54	10.79	2008
2002	6	Tithonia	-	11.47	5.47	2008
2002	6	Charcoal	-	12.99	5.19	2008
2002	6	Sawdust	-	15.61	8.87	2008
2002	6	Control	+	14.35	4.63	2008
2002	6	Control	-	10.99	2.68	2008
2002	6	Tithonia	+	10.82	6.77	2008
2002	6	Charcoal	+	12.14	6.68	2008
2002	6	Sawdust	+	11.49	5.35	2008
2002	6	Tithonia	-	12.85	3.90	2008
2002	6	Charcoal	-	15.04	7.60	2008
2002	6	Sawdust	-	23.68	5.17	2008

2002	6	Control	+	15.18	6.49	2008
2002	6	Control	-	12.60	5.80	2008
1986	22	Tithonia	+	12.00	6.03	2008
1986	22	Charcoal	+	14.22	8.27	2008
1986	22	Sawdust	+	10.23	3.13	2008
1986	22	Tithonia	-	11.64	1.98	2008
1986	22	Charcoal	-	11.15	2.02	2008
1986	22	Sawdust	-	11.10	1.96	2008
1986	22	Control	+	12.26	2.13	2008
1986	22	Control	-	14.39	1.96	2008
1973	35	Tithonia	+	12.85	6.75	2008
1973	35	Charcoal	+	12.64	6.65	2008
1973	35	Sawdust	+	10.02	5.60	2008
1973	35	Tithonia	-	6.77	4.62	2008
1973	35	Charcoal	-	7.94	6.84	2008
1973	35	Sawdust	-	11.90	3.68	2008
1973	35	Control	+	7.88	2.57	2008
1973	35	Control	-	5.70	1.65	2008
1973	35	Tithonia	+	4.64	3.51	2008
1973	35	Charcoal	+	4.82	3.88	2008
1973	35	Sawdust	+	6.70	4.84	2008
1973	35	Tithonia	-	9.42	15.19	2008
1973	35	Charcoal	-	8.69	7.65	2008
1973	35	Sawdust	-	9.94	8.75	2008
1973	35	Control	+	4.88	8.14	2008
1973	35	Control	-	5.57	-	2008
1973	35	Tithonia	+	9.26	6.44	2008
1973	35	Charcoal	+	9.99	3.13	2008
1973	35	Sawdust	+	11.22	5.95	2008
1973	35	Tithonia	-	5.51	3.57	2008
1973	35	Charcoal	-	5.53	1.64	2008
1973	35	Sawdust	-	5.85	2.12	2008
1973	35	Control	+	7.22	3.50	2008
1973	35	Control	-	2.08	1.90	2008
1986	22	Tithonia	+	6.98	2.84	2008
1986	22	Sawdust	+	6.11	5.17	2008
1986	22	Tithonia	-	9.05	3.38	2008
1986	22	Charcoal	-	8.65	2.63	2008
1986	22	Sawdust	-	6.69	3.35	2008
1986	22	Control	+	7.68	4.52	2008
1986	22	Control	-	3.20	1.63	2008
1986	22	Tithonia	+	15.44	7.67	2008

1986	22	Charcoal	+	9.92	5.59	2008
1986	22	Sawdust	+	10.48	5.89	2008
1986	22	Tithonia	-	10.24	5.97	2008
1986	22	Charcoal	-	7.24	5.00	2008
1986	22	Sawdust	-	8.46	5.62	2008
1986	22	Control	+	3.06	1.67	2008
1986	22	Control	-	2.66	0.50	2008
1900	107	Tithonia	+	4.83	1.79	2007
1900	107	Biochar	+	4.74	3.06	2007
1900	107	Sawdust	+	1.97	3.56	2007
1900	107	Control	+	4.20	1.41	2007
1900	107	Tithonia	+	3.71	5.26	2007
1900	107	Biochar	+	2.98	5.76	2007
1900	107	Sawdust	+	2.49	3.65	2007
1900	107	Control	+	1.46	6.55	2007
1930	77	Tithonia	+	3.87	3.84	2007
1930	77	Biochar	+	2.69	6.32	2007
1930	77	Sawdust	+	2.53	2.68	2007
1930	77	Control	+	2.36	3.04	2007
1930	77	Tithonia	+	6.40	4.90	2007
1930	77	Biochar	+	2.68	2.74	2007
1930	77	Sawdust	+	3.00	3.26	2007
1930	77	Control	+	1.20	2.70	2007
2000	7	Tithonia	+	4.00	7.40	2007
2000	7	Biochar	+	4.69	5.43	2007
2000	7	Sawdust	+	4.97	4.65	2007
2000	7	Control	+	3.58	8.31	2007
1996	11	Tithonia	+	5.18	7.98	2007
1996	11	Biochar	+	5.30	5.43	2007
1996	11	Sawdust	+	3.44	5.30	2007
1996	11	Control	+	3.00	6.66	2007
2000	7	Tithonia	+	6.20	7.63	2007
2000	7	Biochar	+	5.40	7.08	2007
2000	7	Sawdust	+	7.40	8.43	2007
2000	7	Control	+	4.00	8.99	2007
1930	77	Tithonia	+	5.70	6.34	2007
1930	77	Biochar	+	5.67	8.51	2007
1930	77	Sawdust	+	7.20	10.17	2007
1930	77	Control	+	2.36	3.69	2007
1986	21	Tithonia	+	3.51	-	2007
1986	21	Biochar	+	3.51	8.18	2007
1986	21	Sawdust	+	4.20	9.21	2007

1986	21	Control	+	1.30	9.09	2007
1986	21	Tithonia	+	2.80	8.35	2007
1986	21	Biochar	+	1.41	8.60	2007
1986	21	Sawdust	+	2.38	2.67	2007
1986	21	Control	+	1.71	7.02	2007
1973	34	Tithonia	+	4.34	7.93	2007
1973	34	Biochar	+	3.13	5.72	2007
1973	34	Sawdust	+	4.39	7.88	2007
1973	34	Control	+	1.00	1.65	2007
1973	34	Tithonia	+	2.41	4.60	2007
1973	34	Biochar	+	3.23	6.54	2007
1973	34	Sawdust	+	1.54	1.72	2007
1973	34	Control	+	-	-	2007
2002	5	Tithonia	+	8.56	8.21	2007
2002	5	Biochar	+	8.88	11.77	2007
2002	5	Sawdust	+	7.21	10.56	2007
2002	5	Control	+	4.30	11.22	2007
2002	5	Tithonia	+	7.40	11.53	2007
2002	5	Biochar	+	8.10	8.72	2007
2002	5	Sawdust	+	7.00	11.62	2007
2002	5	Control	+	6.50	7.34	2007
1950	57	Tithonia	+	4.04	7.42	2007
1950	57	Biochar	+	5.47	8.42	2007
1950	57	Sawdust	+	1.16	3.12	2007
1950	57	Control	+	3.00	9.57	2007
1950	57	Tithonia	+	4.50	6.68	2007
1950	57	Biochar	+	5.46	8.04	2007
1950	57	Sawdust	+	5.16	8.91	2007
1950	57	Control	+	2.56	1.51	2007
1996	11	Tithonia	+	6.00	7.23	2007
1996	11	Biochar	+	6.20	7.79	2007
1996	11	Sawdust	+	7.30	9.72	2007
1996	11	Control	+	4.00	12.65	2007
1997	10	Tithonia	+	6.20	8.46	2007
1997	10	Biochar	+	9.10	10.12	2007
1997	10	Sawdust	+	7.00	9.31	2007
1997	10	Control	+	-	-	2007
1900	106	Tithonia	+	10.71	5.68	2006
1900	106	Biochar	+	6.80	4.27	2006
1900	106	Manure	+	6.50	4.12	2006
1900	106	Sawdust	+	6.89	3.96	2006
1900	106	Tithonia	-	15.66	8.08	2006

1900	106	Biochar	-	3.62	1.44	2006
1900	106	Manure	-	5.56	1.84	2006
1900	106	Sawdust	-	5.24	1.66	2006
1900	106	Control	+	6.39	2.53	2006
1900	106	Control	-	2.58	0.87	2006
1900	106	Tithonia	+	13.15	8.66	2006
1900	106	Biochar	+	9.44	6.86	2006
1900	106	Manure	+	8.98	6.09	2006
1900	106	Sawdust	+	11.53	5.81	2006
1900	106	Tithonia	-	13.99	8.52	2006
1900	106	Biochar	-	5.58	1.88	2006
1900	106	Manure	-	14.31	8.04	2006
1900	106	Sawdust	-	4.86	3.71	2006
1900	106	Control	+	10.19	4.52	2006
1900	106	Control	-	4.97	1.67	2006
1900	106	Tithonia	+	17.61	9.53	2006
1900	106	Biochar	+	10.21	6.64	2006
1900	106	Manure	+	11.24	6.76	2006
1900	106	Sawdust	+	7.43	4.27	2006
1900	106	Tithonia	-	20.62	8.83	2006
1900	106	Biochar	-	8.00	4.08	2006
1900	106	Manure	-	13.45	6.12	2006
1900	106	Sawdust	-	1.13	0.45	2006
1900	106	Control	+	11.03	6.01	2006
1900	106	Control	-	2.99	0.92	2006
1930	76	Tithonia	+	12.09	6.81	2006
1930	76	Biochar	+	5.62	6.63	2006
1930	76	Manure	+	13.81	8.69	2006
1930	76	Sawdust	+	7.92	6.10	2006
1930	76	Tithonia	-	13.92	10.70	2006
1930	76	Biochar	-	4.36	3.37	2006
1930	76	Manure	-	8.74	7.88	2006
1930	76	Sawdust	-	6.82	5.91	2006
1930	76	Control	+	9.42	7.72	2006
1930	76	Control	-	2.14	1.07	2006
1930	76	Tithonia	+	11.04	8.20	2006
1930	76	Biochar	+	7.33	6.84	2006
1930	76	Manure	+	11.53	7.84	2006
1930	76	Sawdust	+	9.07	6.31	2006
1930	76	Tithonia	-	11.84	4.43	2006
1930	76	Biochar	-	0.75	0.60	2006
1930	76	Manure	-	9.15	4.66	2006

1930	76	Sawdust	-	0.38	0.28	2006
1930	76	Control	+	8.77	5.33	2006
1930	76	Control	-	3.57	3.01	2006
1930	76	Tithonia	+	13.60	9.60	2006
1930	76	Biochar	+	12.72	10.85	2006
1930	76	Manure	+	15.32	10.57	2006
1930	76	Sawdust	+	11.49	8.19	2006
1930	76	Tithonia	-	16.53	12.14	2006
1930	76	Biochar	-	6.03	3.87	2006
1930	76	Manure	-	12.83	8.06	2006
1930	76	Sawdust	-	8.31	6.63	2006
1930	76	Control	+	12.31	8.89	2006
1930	76	Control	-	8.31	5.57	2006
1986	20	Tithonia	+	13.47	6.83	2006
1986	20	Biochar	+	5.10	4.72	2006
1986	20	Manure	+	9.05	6.39	2006
1986	20	Sawdust	+	5.79	4.42	2006
1986	20	Tithonia	-	13.28	6.20	2006
1986	20	Biochar	-	2.67	0.67	2006
1986	20	Manure	-	9.75	6.73	2006
1986	20	Sawdust	-	2.88	2.02	2006
1986	20	Control	+	4.89	5.21	2006
1986	20	Control	-	3.29	0.72	2006
1986	20	Tithonia	+	12.71	8.24	2006
1986	20	Biochar	+	5.63	4.33	2006
1986	20	Manure	+	12.89	7.34	2006
1986	20	Sawdust	+	6.03	3.54	2006
1986	20	Tithonia	-	13.33	8.78	2006
1986	20	Biochar	-	7.78	6.52	2006
1986	20	Manure	-	9.81	6.10	2006
1986	20	Sawdust	-	5.15	2.80	2006
1986	20	Control	+	5.86	2.96	2006
1986	20	Control	-	7.14	3.14	2006
1973	33	Tithonia	+	10.34	3.94	2006
1973	33	Biochar	+	6.36	2.83	2006
1973	33	Manure	+	9.76	4.08	2006
1973	33	Sawdust	+	5.49	2.13	2006
1973	33	Tithonia	-	7.62	2.99	2006
1973	33	Biochar	-	6.38	1.16	2006
1973	33	Manure	-	6.37	1.71	2006
1973	33	Sawdust	-	4.76	1.57	2006
1973	33	Control	+	7.02	3.80	2006

1973	33	Tithonia	+	11.79	5.59	2006
1973	33	Biochar	+	7.96	4.67	2006
1973	33	Manure	+	9.98	5.42	2006
1973	33	Sawdust	+	5.82	3.56	2006
1973	33	Tithonia	-	14.64	6.77	2006
1973	33	Biochar	-	3.79	1.20	2006
1973	33	Manure	-	7.93	4.48	2006
1973	33	Sawdust	-	4.60	1.74	2006
1973	33	Control	+	3.71	2.37	2006
1973	33	Control	-	2.48	0.71	2006
1973	33	Tithonia	+	13.90	6.73	2006
1973	33	Biochar	+	6.38	4.14	2006
1973	33	Manure	+	10.90	5.31	2006
1973	33	Sawdust	+	7.77	5.00	2006
1973	33	Tithonia	-	11.05	8.60	2006
1973	33	Biochar	-	3.44	0.85	2006
1973	33	Manure	-	8.27	4.70	2006
1973	33	Sawdust	-	1.44	0.61	2006
1973	33	Control	+	5.14	3.31	2006
1973	33	Control	-	4.09	2.59	2006
1995	11	Tithonia	+	12.29	8.67	2006
1995	11	Biochar	+	5.78	6.55	2006
1995	11	Manure	+	10.64	6.59	2006
1995	11	Sawdust	+	6.81	4.85	2006
1995	11	Tithonia	-	13.31	9.68	2006
1995	11	Biochar	-	3.45	2.84	2006
1995	11	Manure	-	6.48	7.00	2006
1995	11	Sawdust	-	4.70	4.44	2006
1995	11	Control	+	0.81	1.09	2006
1995	11	Control	-	1.05	1.02	2006
1995	11	Tithonia	+	9.66	6.23	2006
1995	11	Biochar	+	5.15	4.41	2006
1995	11	Manure	+	8.30	6.14	2006
1995	11	Sawdust	+	4.78	3.06	2006
1995	11	Tithonia	-	6.78	5.50	2006
1995	11	Biochar	-	1.29	0.14	2006
1995	11	Manure	-	5.34	3.70	2006
1995	11	Sawdust	-	2.12	0.67	2006
1995	11	Control	+	6.78	4.77	2006
1995	11	Control	-	5.16	2.56	2006
1995	11	Tithonia	+	1.82	0.15	2006
1995	11	Biochar	+	2.86	0.41	2006

1995	11	Manure	+	1.98	0.15	2006
1995	11	Sawdust	+	2.29	0.33	2006
1995	11	Tithonia	-	2.25	0.80	2006
1995	11	Biochar	-	1.07	0.05	2006
1995	11	Manure	-	1.13	0.49	2006
1995	11	Sawdust	-	1.50	0.39	2006
1995	11	Control	+	3.32	1.32	2006
1995	11	Control	-	2.03	0.86	2006
1986	20	Tithonia	+	12.00	6.39	2006
1986	20	Biochar	+	9.22	3.99	2006
1986	20	Manure	+	12.47	6.04	2006
1986	20	Sawdust	+	9.09	4.69	2006
1986	20	Tithonia	-	11.64	6.96	2006
1986	20	Biochar	-	7.15	3.80	2006
1986	20	Manure	-	12.63	5.70	2006
1986	20	Sawdust	-	5.81	3.23	2006
1986	20	Control	+	9.29	6.25	2006
1986	20	Control	-	7.31	4.79	2006
2002	4	Tithonia	+	10.71	8.20	2006
2002	4	Biochar	+	10.93	7.78	2006
2002	4	Manure	+	10.71	7.80	2006
2002	4	Sawdust	+	4.75	6.58	2006
2002	4	Tithonia	-	10.71	8.91	2006
2002	4	Biochar	-	5.06	5.81	2006
2002	4	Sawdust	-	1.67	2.22	2006
2002	4	Tithonia	+	9.44	7.40	2006
2002	4	Biochar	+	6.79	3.49	2006
2002	4	Manure	+	11.31	8.37	2006
2002	4	Sawdust	+	9.56	6.95	2006
2002	4	Tithonia	-	18.16	11.80	2006
2002	4	Biochar	-	6.13	6.04	2006
2002	4	Manure	-	14.12	10.88	2006
2002	4	Sawdust	-	6.26	7.61	2006
2002	4	Control	+	8.58	7.94	2006
2002	4	Control	-	5.86	5.95	2006
2002	4	Tithonia	+	12.79	11.95	2006
2002	4	Biochar	+	8.40	7.12	2006
2002	4	Manure	+	10.88	8.68	2006
2002	4	Sawdust	+	6.12	7.29	2006
2002	4	Tithonia	-	11.55	7.56	2006
2002	4	Biochar	-	10.98	8.90	2006
2002	4	Manure	-	8.54	5.87	2006

2002	4	Sawdust	-	6.74	4.89	2006
2002	4	Control	+	10.29	8.81	2006
2002	4	Control	-	8.87	5.91	2006
1996	10	Tithonia	+	10.82	8.58	2006
1996	10	Biochar	+	6.76	7.10	2006
1996	10	Manure	+	6.50	6.23	2006
1996	10	Sawdust	+	7.71	6.97	2006
1996	10	Tithonia	-	7.10	6.92	2006
1996	10	Biochar	-	6.18	5.54	2006
1996	10	Manure	-	12.48	10.25	2006
1996	10	Sawdust	-	3.75	2.87	2006
1996	10	Control	+	9.48	6.28	2006
1996	10	Control	-	6.64	5.54	2006
1996	10	Tithonia	+	9.71	7.92	2006
1996	10	Biochar	+	6.07	4.57	2006
1996	10	Manure	+	10.92	9.29	2006
1996	10	Sawdust	+	7.35	4.83	2006
1996	10	Tithonia	-	10.08	7.21	2006
1996	10	Biochar	-	4.23	3.90	2006
1996	10	Manure	-	9.68	9.35	2006
1996	10	Sawdust	-	3.04	2.70	2006
1996	10	Control	+	8.21	9.53	2006
1997	9	Control	-	5.05	4.97	2006
1997	9	Tithonia	+	7.22	5.82	2006
1997	9	Biochar	+	7.37	6.38	2006
1997	9	Manure	+	12.81	6.82	2006
1997	9	Sawdust	+	5.95	5.89	2006
1997	9	Tithonia	-	7.32	4.81	2006
1997	9	Biochar	-	4.30	3.96	2006
1997	9	Manure	-	4.60	3.29	2006
1997	9	Sawdust	-	6.65	5.89	2006
2000	6	Tithonia	+	9.24	7.36	2006
2000	6	Biochar	+	9.28	7.76	2006
2000	6	Manure	+	9.43	9.41	2006
2000	6	Sawdust	+	5.74	7.48	2006
2000	6	Tithonia	-	11.91	10.03	2006
2000	6	Biochar	-	5.28	8.80	2006
2000	6	Manure	-	9.33	5.81	2006
2000	6	Sawdust	-	6.53	5.69	2006
2000	6	Control	+	13.15	10.44	2006
2000	6	Control	-	7.30	8.89	2006
2001	5	Tithonia	+	8.05	7.77	2006

2001	5	Biochar	+	6.77	6.90	2006
2001	5	Manure	+	7.27	7.27	2006
2001	5	Sawdust	+	5.68	5.04	2006
2001	5	Tithonia	-	7.54	7.21	2006
2001	5	Biochar	-	5.81	6.59	2006
2001	5	Manure	-	6.66	10.07	2006
2001	5	Sawdust	-	3.59	6.07	2006
2001	5	Control	+	4.60	5.06	2006
2001	5	Control	-	6.75	6.57	2006
2000	6	Tithonia	+	10.22	6.87	2006
2000	6	Biochar	+	9.93	8.17	2006
2000	6	Manure	+	10.50	9.38	2006
2000	6	Sawdust	+	7.87	7.27	2006
2000	6	Tithonia	-	10.44	9.40	2006
2000	6	Biochar	-	6.65	4.66	2006
2000	6	Manure	-	9.02	8.14	2006
2000	6	Sawdust	-	8.03	6.63	2006
2000	6	Control	+	10.82	8.06	2006
2000	6	Control	-	7.78	7.97	2006
1950	56	Tithonia	+	11.74	10.06	2006
1950	56	Biochar	+	6.37	5.93	2006
1950	56	Manure	+	10.55	9.23	2006
1950	56	Sawdust	+	5.98	6.21	2006
1950	56	Tithonia	-	7.85	7.76	2006
1950	56	Biochar	-	3.66	3.34	2006
1950	56	Manure	-	6.77	4.97	2006
1950	56	Sawdust	-	1.92	1.30	2006
1950	56	Control	+	6.98	4.77	2006
1950	56	Control	-	2.61	1.72	2006
1950	56	Tithonia	+	11.82	10.02	2006
1950	56	Biochar	+	7.33	7.15	2006
1950	56	Manure	+	16.01	10.55	2006
1950	56	Sawdust	+	7.98	6.60	2006
1950	56	Tithonia	-	10.39	6.94	2006
1950	56	Biochar	-	5.87	3.08	2006
1950	56	Manure	-	13.01	13.80	2006
1950	56	Sawdust	-	6.01	4.36	2006
1950	56	Control	+	14.72	8.94	2006
1950	56	Control	-	5.25	3.55	2006
1950	56	Tithonia	+	13.07	9.52	2006
1950	56	Biochar	+	5.54	8.45	2006
1950	56	Manure	+	16.65	11.44	2006

1950	56	Sawdust	+	2.53	2.19	2006
1950	56	Tithonia	-	11.10	10.89	2006
1950	56	Biochar	-	3.88	2.91	2006
1950	56	Manure	-	15.07	8.68	2006
1950	56	Sawdust	-	1.76	0.91	2006
1950	56	Control	+	12.93	9.20	2006
1950	56	Control	-	1.78	0.79	2006
1900	105	Control	-	1.10	0.22	2005
1900	105	Control	+	4.67	3.02	2005
1900	105	Tithonia	+	8.14	3.78	2005
1900	105	Biochar	+	5.03	2.37	2005
1900	105	Manure	-	7.67	5.57	2005
1900	105	Sawdust	+	8.61	2.66	2005
1900	105	Tithonia	-	11.08	2.01	2005
1900	105	Biochar	-	1.17	0.81	2005
1900	105	Manure	-	6.69	2.78	2005
1900	105	Sawdust	-	1.27	0.33	2005
1900	105	Control	-	2.98	0.56	2005
1900	105	Control	+	7.23	4.57	2005
1900	105	Tithonia	+	16.40	8.04	2005
1900	105	Biochar	+	9.75	5.74	2005
1900	105	Manure	-	10.60	6.53	2005
1900	105	Sawdust	+	10.16	5.68	2005
1900	105	Tithonia	-	12.60	8.41	2005
1900	105	Biochar	-	6.19	2.49	2005
1900	105	Manure	-	7.92	2.73	2005
1900	105	Sawdust	-	6.80	3.37	2005
1900	105	Control	-	2.90	1.37	2005
1900	105	Control	+	5.83	3.92	2005
1900	105	Tithonia	+	10.34	5.85	2005
1900	105	Biochar	+	10.19	5.31	2005
1900	105	Manure	-	7.57	4.64	2005
1900	105	Sawdust	+	5.93	3.53	2005
1900	105	Tithonia	-	11.81	3.35	2005
1900	105	Biochar	-	6.02	3.10	2005
1900	105	Manure	-	11.09	4.06	2005
1900	105	Sawdust	-	3.60	2.64	2005
1922	83	Control	-	1.66	0.12	2005
1922	83	Control	+	2.44	0.76	2005
1922	83	Tithonia	+	6.52	5.23	2005
1922	83	Biochar	+	3.33	3.95	2005
1922	83	Manure	-	3.23	3.59	2005

1922	83	Sawdust	+	1.23	0.42	2005
1922	83	Tithonia	-	13.19	7.09	2005
1922	83	Biochar	-	1.62	1.12	2005
1922	83	Manure	-	3.07	1.04	2005
1922	83	Sawdust	-	0.53	0.49	2005
1930	75	Control	-	3.31	0.82	2005
1930	75	Control	+	5.16	4.61	2005
1930	75	Tithonia	+	7.56	9.53	2005
1930	75	Biochar	+	4.09	4.89	2005
1930	75	Manure	-	6.24	6.09	2005
1930	75	Sawdust	+	5.33	5.11	2005
1930	75	Tithonia	-	7.84	6.57	2005
1930	75	Biochar	-	1.33	0.28	2005
1930	75	Manure	-	6.08	3.26	2005
1930	75	Sawdust	-	0.98	0.01	2005
1921	84	Control	-	2.01	1.29	2005
1921	84	Control	+	7.87	5.56	2005
1921	84	Tithonia	+	6.51	5.61	2005
1921	84	Biochar	+	5.71	5.44	2005
1921	84	Manure	-	7.40	6.67	2005
1921	84	Sawdust	+	7.11	5.92	2005
1921	84	Tithonia	-	11.57	5.02	2005
1921	84	Biochar	-	3.33	1.96	2005
1921	84	Manure	-	4.89	3.76	2005
1921	84	Sawdust	-	2.27	1.91	2005
1986	19	Control	-	0.86	-	2005
1986	19	Control	+	7.97	5.52	2005
1986	19	Tithonia	+	13.65	7.39	2005
1986	19	Biochar	+	8.55	4.36	2005
1986	19	Manure	-	10.43	5.78	2005
1986	19	Sawdust	+	4.07	1.30	2005
1986	19	Tithonia	-	6.78	6.47	2005
1986	19	Biochar	-	3.21	1.70	2005
1986	19	Manure	-	5.00	5.45	2005
1986	19	Sawdust	-	4.93	2.64	2005
1986	19	Control	-	2.34	1.18	2005
1986	19	Control	+	7.23	4.28	2005
1986	19	Tithonia	+	5.42	5.97	2005
1986	19	Biochar	+	10.02	5.62	2005
1986	19	Manure	-	9.01	6.80	2005
1986	19	Sawdust	+	8.28	5.49	2005
1986	19	Tithonia	-	9.55	4.74	2005

1986	19	Biochar	-	7.72	5.31	2005
1986	19	Manure	-	8.70	7.05	2005
1986	19	Sawdust	-	6.28	4.78	2005
1973	32	Control	-	2.83	0.12	2005
1973	32	Control	+	7.96	3.09	2005
1973	32	Tithonia	+	7.12	3.48	2005
1973	32	Biochar	+	4.64	2.14	2005
1973	32	Manure	-	9.04	3.91	2005
1973	32	Sawdust	+	4.01	3.36	2005
1973	32	Tithonia	-	9.04	4.34	2005
1973	32	Biochar	-	3.36	0.28	2005
1973	32	Manure	-	7.05	2.28	2005
1973	32	Sawdust	-	3.93	1.26	2005
1973	32	Control	-	3.01	0.49	2005
1973	32	Control	+	5.55	2.74	2005
1973	32	Tithonia	+	2.32	2.30	2005
1973	32	Biochar	+	4.66	2.22	2005
1973	32	Manure	-	6.77	3.64	2005
1973	32	Sawdust	+	6.84	3.62	2005
1973	32	Tithonia	-	8.98	4.98	2005
1973	32	Biochar	-	4.61	1.48	2005
1973	32	Manure	-	9.26	3.78	2005
1973	32	Sawdust	-	3.22	2.35	2005
1973	32	Control	-	2.76	1.23	2005
1973	32	Control	+	1.88	2.49	2005
1973	32	Tithonia	+	3.44	3.95	2005
1973	32	Biochar	+	8.13	5.54	2005
1973	32	Manure	-	6.79	5.00	2005
1973	32	Sawdust	+	3.77	1.97	2005
1973	32	Tithonia	-	8.31	5.53	2005
1973	32	Biochar	-	3.20	0.68	2005
1973	32	Manure	-	6.06	2.48	2005
1973	32	Sawdust	-	1.36	0.59	2005
1973	32	Control	-	2.17	0.43	2005
1973	32	Control	+	10.99	8.53	2005
1973	32	Tithonia	+	7.32	5.82	2005
1973	32	Biochar	+	10.04	5.23	2005
1973	32	Manure	-	3.13	5.55	2005
1973	32	Sawdust	+	8.65	5.39	2005
1995	10	Control	-	2.29	0.50	2005
1995	10	Control	+	5.60	3.91	2005
1995	10	Tithonia	+	20.91	6.36	2005

1995	10	Biochar	+	6.35	5.77	2005
1995	10	Manure	-	5.91	3.01	2005
1995	10	Tithonia	-	9.12	5.79	2005
1995	10	Biochar	-	4.66	4.15	2005
1995	10	Manure	-	12.01	6.76	2005
1995	10	Sawdust	-	2.34	1.70	2005
1995	10	Control	-	1.54	0.60	2005
1995	10	Control	+	3.62	3.76	2005
1995	10	Tithonia	+	9.44	6.69	2005
1995	10	Biochar	+	1.39	4.57	2005
1995	10	Manure	-	15.38	6.24	2005
1995	10	Sawdust	+	6.46	3.26	2005
1995	10	Tithonia	-	3.44	2.48	2005
1995	10	Biochar	-	2.12	2.22	2005
1995	10	Manure	-	3.41	4.01	2005
1995	10	Sawdust	-	3.10	2.31	2005
1995	10	Control	-	4.74	0.70	2005
1995	10	Tithonia	+	12.25	2.95	2005
1995	10	Biochar	+	8.23	3.86	2005
1995	10	Manure	-	10.04	5.23	2005
1995	10	Sawdust	+	7.52	3.82	2005
1995	10	Tithonia	-	13.72	2.19	2005
1995	10	Biochar	-	4.99	0.60	2005
1995	10	Manure	-	7.60	1.90	2005
1995	10	Sawdust	-	2.98	1.24	2005
1986	19	Control	-	2.87	2.09	2005
1986	19	Control	+	7.22	7.18	2005
1986	19	Tithonia	+	12.71	7.66	2005
1986	19	Biochar	+	10.41	6.67	2005
1986	19	Manure	-	14.15	7.86	2005
1986	19	Sawdust	+	7.66	6.96	2005
1986	19	Tithonia	-	15.85	8.45	2005
1986	19	Biochar	-	6.78	4.63	2005
1986	19	Manure	-	11.61	5.17	2005
1986	19	Sawdust	-	5.05	3.86	2005
2002	3	Control	-	6.06	4.56	2005
2002	3	Control	+	6.89	5.56	2005
2002	3	Tithonia	+	7.19	5.95	2005
2002	3	Biochar	+	13.29	7.91	2005
2002	3	Manure	-	11.99	6.20	2005
2002	3	Sawdust	+	6.70	5.66	2005
2002	3	Tithonia	-	8.90	6.96	2005

2002	3	Biochar	-	7.03	4.99	2005
2002	3	Manure	-	6.16	5.16	2005
2002	3	Sawdust	-	11.37	4.55	2005
2002	3	Control	-	4.82	3.24	2005
2002	3	Control	+	9.34	9.69	2005
2002	3	Tithonia	+	12.65	8.67	2005
2002	3	Biochar	+	11.92	6.89	2005
2002	3	Manure	-	7.52	7.23	2005
2002	3	Sawdust	+	8.31	5.34	2005
2002	3	Tithonia	-	13.33	8.84	2005
2002	3	Biochar	-	8.90	9.97	2005
2002	3	Manure	-	10.64	7.56	2005
2002	3	Sawdust	-	8.89	6.14	2005
2002	3	Control	-	7.52	8.50	2005
2002	3	Control	+	8.50	7.52	2005
2002	3	Tithonia	+	16.94	7.49	2005
2002	3	Biochar	+	9.35	5.70	2005
2002	3	Manure	-	12.04	6.47	2005
2002	3	Sawdust	+	12.11	5.42	2005
2002	3	Tithonia	-	8.94	7.31	2005
2002	3	Biochar	-	5.93	5.00	2005
2002	3	Manure	-	10.26	6.13	2005
2002	3	Sawdust	-	4.27	4.35	2005

Data table for chapter 2, Figure 2.5

Farmer	Village	Years since conversion to 2010	Treatment	Fertilizer	ABA (pmol /g)
Martim Tatim Moro	kiptaruswo	40	Tithonia	+	2.55
Martim Tatim Moro	kiptaruswo	40	Sawdust	+	2.46
Martim Tatim Moro	kiptaruswo	40	Control	+	2.54
Martim Tatim Moro	kiptaruswo	40	Tithonia	-	3.38
Martim Tatim Moro	kiptaruswo	40	Biochar	-	6.54
Martim Tatim Moro	kiptaruswo	40	Sawdust	-	2.83
Martim Tatim Moro	kiptaruswo	40	Control	-	1.95
Martim Tatim Moro	kiptaruswo	40	Tithonia	+	3.25
Martim Tatim Moro	kiptaruswo	40	Sawdust	+	1.37
Martim Tatim Moro	kiptaruswo	40	Control	+	2.39
Martim Tatim Moro	kiptaruswo	40	Tithonia	-	2.89
Martim Tatim Moro	kiptaruswo	40	Biochar	-	3.38
Martim Tatim Moro	kiptaruswo	40	Sawdust	-	3.54
Martim Tatim Moro	kiptaruswo	40	Control	-	3.85
Martim Tatim Moro	kiptaruswo	40	Farmer Practices	+	11.26
Jackton Liaga	kapsengere	100	Tithonia	+	25.88
Jackton Liaga	kapsengere	100	Biochar	+	9.10
Jackton Liaga	kapsengere	100	Control	+	7.91
Jackton Liaga	kapsengere	100	Tithonia	-	4.32
Jackton Liaga	kapsengere	100	Biochar	-	4.01
Jackton Liaga	kapsengere	100	Sawdust	-	3.71
Jackton Liaga	kapsengere	100	Control	-	7.45
Jackton Liaga	kapsengere	100	Tithonia	+	18.25
Jackton Liaga	kapsengere	100	Biochar	+	18.41
Jackton Liaga	kapsengere	100	Sawdust	+	6.70
Jackton Liaga	kapsengere	100	Tithonia	-	4.26
Jackton Liaga	kapsengere	100	Biochar	-	5.15
Jackton Liaga	kapsengere	100	Sawdust	-	4.53
Jackton Liaga	kapsengere	100	Control	-	6.85
Jackton Liaga	kapsengere	100	Farmer Practices	+	7.33
Robert Koech	kereri	20	Tithonia	+	4.48
Robert Koech	kereri	20	Biochar	+	3.96
Robert Koech	kereri	20	Sawdust	+	2.33
Robert Koech	kereri	20	Control	+	2.61
Robert Koech	kereri	20	Tithonia	-	3.76
Robert Koech	kereri	20	Biochar	-	3.28
Robert Koech	kereri	20	Sawdust	-	3.79
Robert Koech	kereri	20	Control	-	3.24
Robert Koech	kereri	20	Tithonia	+	10.67

Robert Koech	kereri	20	Biochar	+	4.81
Robert Koech	kereri	20	Sawdust	+	5.84
Robert Koech	kereri	20	Control	+	4.47
Robert Koech	kereri	20	Tithonia	-	5.39
Robert Koech	kereri	20	Biochar	-	3.59
Robert Koech	kereri	20	Sawdust	-	4.00
Robert Koech	kereri	20	Control	-	4.25
Robert Koech	kereri	20	Farmer Practices	+	3.49
Lily Muthai	koibem	10	Biochar	+	5.12
Lily Muthai	koibem	10	Sawdust	+	3.88
Lily Muthai	koibem	10	Control	+	3.91
Lily Muthai	koibem	10	Tithonia	-	3.02
Lily Muthai	koibem	10	Biochar	-	3.62
Lily Muthai	koibem	10	Sawdust	-	3.99
Lily Muthai	koibem	10	Tithonia	+	3.10
Lily Muthai	koibem	10	Biochar	+	2.45
Lily Muthai	koibem	10	Sawdust	+	3.36
Lily Muthai	koibem	10	Control	+	5.62
Lily Muthai	koibem	10	Tithonia	-	7.69
Lily Muthai	koibem	10	Biochar	-	4.05
Lily Muthai	koibem	10	Sawdust	-	6.21
Lily Muthai	koibem	10	Control	-	6.43
Lily Muthai	koibem	10	Farmer Practices	+	5.44
Lily Muthai	koibem	10	Tithonia	+	2.75
Lily Muthai	koibem	10	Control	-	3.21
Julias Songok	Kereri	20	Tithonia	+	5.35
Julias Songok	Kereri	20	Sawdust	+	6.57
Julias Songok	Kereri	20	Control	+	10.92
Julias Songok	Kereri	20	Tithonia	-	5.78
Julias Songok	Kereri	20	Biochar	-	3.64
Julias Songok	Kereri	20	Sawdust	-	4.29
Julias Songok	Kereri	20	Control	-	5.04
Julias Songok	Kereri	20	Farmer Practices	+	4.99
Martim Arap Suguti	Siksiket	10	Biochar	+	3.94
Martim Arap Suguti	Siksiket	10	Sawdust	+	2.30
Martim Arap Suguti	Siksiket	10	Tithonia	-	2.87
Martim Arap Suguti	Siksiket	10	Tithonia	+	2.56
Martim Arap Suguti	Siksiket	10	Biochar	+	3.01
Martim Arap Suguti	Siksiket	10	Sawdust	+	3.34
Martim Arap Suguti	Siksiket	10	Biochar	-	3.17
Martim Arap Suguti	Siksiket	10	Farmer Practices	+	6.86

Martim Arap Suguti	Siksiket	10	Tithonia	+	2.00
Martim Arap Suguti	Siksiket	10	Control	+	3.29
Martim Arap Suguti	Siksiket	10	Biochar	-	4.26
Martim Arap Suguti	Siksiket	10	Sawdust	-	4.08
Martim Arap Suguti	Siksiket	10	Control	-	3.22
Simon Bi	Koibem	10	Tithonia	+	6.29
Simon Bi	Koibem	10	Control	+	12.93
Simon Bi	Koibem	10	Tithonia	-	3.46
Simon Bi	Koibem	10	Tithonia	+	5.19
Simon Bi	Koibem	10	Biochar	+	3.84
Simon Bi	Koibem	10	Sawdust	+	3.98
Simon Bi	Koibem	10	Control	+	5.16
Simon Bi	Koibem	10	Tithonia	-	7.95
Simon Bi	Koibem	10	Biochar	-	5.91
Simon Bi	Koibem	10	Sawdust	-	6.76
Simon Bi	Koibem	10	Control	-	3.73
Simon Bi	Koibem	10	Farmer Practices	+	6.92
Simon Bi	Koibem	10	Biochar	+	2.90
Simon Bi	Koibem	10	Sawdust	+	3.46
Simon Bi	Koibem	10	Biochar	-	2.00
Simon Bi	Koibem	10	Sawdust	-	3.58
Simon Bi	Koibem	10	Control	-	3.16
Musa Amuhanda	Kapsengere	100	Biochar	+	12.32
Musa Amuhanda	Kapsengere	100	Biochar	-	9.14
Musa Amuhanda	Kapsengere	100	Sawdust	-	11.27
Musa Amuhanda	Kapsengere	100	Tithonia	+	53.99
Musa Amuhanda	Kapsengere	100	Control	+	11.92
Musa Amuhanda	Kapsengere	100	Biochar	+	12.84
Musa Amuhanda	Kapsengere	100	Biochar	-	5.65
Musa Amuhanda	Kapsengere	100	Sawdust	+	25.60
Musa Amuhanda	Kapsengere	100	Sawdust	-	8.79
Musa Amuhanda	Kapsengere	100	Tithonia	+	14.48
Musa Amuhanda	Kapsengere	100	Tithonia	-	4.40
Musa Amuhanda	Kapsengere	100	Control	+	25.63
Musa Amuhanda	Kapsengere	100	Control	-	5.57
Musa Amuhanda	Kapsengere	100	Farmer Practices	+	9.25
Musa Amuhanda	Kapsengere	100	Sawdust	+	4.25
Musa Amuhanda	Kapsengere	100	Tithonia	-	4.23
Musa Amuhanda	Kapsengere	100	Control	-	3.24
Silas Rotich	Siksiket	10	Biochar	-	5.17
Silas Rotich	Siksiket	10	Sawdust	-	3.52
Silas Rotich	Siksiket	10	Tithonia	+	3.58
Silas Rotich	Siksiket	10	Control	+	2.82

Silas Rotich	Siksiket	10	Control	-	2.70
Silas Rotich	Siksiket	10	Sawdust	+	3.05
Silas Rotich	Siksiket	10	Tithonia	-	2.79
Silas Rotich	Siksiket	10	Biochar	+	6.65
Silas Rotich	Siksiket	10	Biochar	-	4.96
Silas Rotich	Siksiket	10	Sawdust	+	6.98
Silas Rotich	Siksiket	10	Sawdust	-	5.49
Silas Rotich	Siksiket	10	Tithonia	+	2.68
Silas Rotich	Siksiket	10	Tithonia	-	4.01
Silas Rotich	Siksiket	10	Control	+	6.04
Silas Rotich	Siksiket	10	Control	-	3.75
Silas Rotich	Siksiket	10	Farmer Practices	+	9.90
Rael Serem	Bonjoge	20	Biochar	+	19.11
Rael Serem	Bonjoge	20	Biochar	-	4.06
Rael Serem	Bonjoge	20	Sawdust	+	5.45
Rael Serem	Bonjoge	20	Sawdust	-	5.95
Rael Serem	Bonjoge	20	Tithonia	+	8.15
Rael Serem	Bonjoge	20	Tithonia	-	4.87
Rael Serem	Bonjoge	20	Control	+	2.60
Rael Serem	Bonjoge	20	Control	-	1.21
Rael Serem	Bonjoge	20	Biochar	+	2.77
Rael Serem	Bonjoge	20	Biochar	-	2.63
Rael Serem	Bonjoge	20	Sawdust	+	2.75
Rael Serem	Bonjoge	20	Sawdust	-	2.39
Rael Serem	Bonjoge	20	Tithonia	+	2.54
Rael Serem	Bonjoge	20	Tithonia	-	1.62
Rael Serem	Bonjoge	20	Control	+	1.90
Rael Serem	Bonjoge	20	Control	-	1.67
Rael Serem	Bonjoge	20	Farmer Practices	+	2.02
Elkana Kadonge	Kapkerer	90	Biochar	+	8.35
Elkana Kadonge	Kapkerer	90	Biochar	-	6.84
Elkana Kadonge	Kapkerer	90	Sawdust	+	8.09
Elkana Kadonge	Kapkerer	90	Sawdust	-	6.15
Elkana Kadonge	Kapkerer	90	Tithonia	+	11.26
Elkana Kadonge	Kapkerer	90	Tithonia	-	5.04
Elkana Kadonge	Kapkerer	90	Control	+	5.24
Elkana Kadonge	Kapkerer	90	Control	-	6.54
Elkana Kadonge	Kapkerer	90	Farmer Practices	+	17.12
Elkana Kadonge	Kapkerer	90	Biochar	+	3.03
Elkana Kadonge	Kapkerer	90	Biochar	-	2.54
Elkana Kadonge	Kapkerer	90	Sawdust	-	3.53
Elkana Kadonge	Kapkerer	90	Tithonia	+	3.23

Elkana Kadonge	Kapkerer	90	Control	+	5.87
Elkana Kadonge	Kapkerer	90	Control	-	2.39
Elkana Kadonge	Kapkerer	90	Sawdust	+	14.75
Elkana Kadonge	Kapkerer	90	Tithonia	+	3.23
Esther Cheroitch	Kecheri	5	Biochar	+	9.22
Esther Cheroitch	Kecheri	5	Biochar	-	4.85
Esther Cheroitch	Kecheri	5	Sawdust	+	4.09
Esther Cheroitch	Kecheri	5	Sawdust	-	7.57
Esther Cheroitch	Kecheri	5	Tithonia	+	3.24
Esther Cheroitch	Kecheri	5	Tithonia	-	3.61
Esther Cheroitch	Kecheri	5	Control	+	2.00
Esther Cheroitch	Kecheri	5	Control	-	3.46
Esther Cheroitch	Kecheri	5	Biochar	+	7.23
Esther Cheroitch	Kecheri	5	Biochar	-	6.85
Esther Cheroitch	Kecheri	5	Sawdust	+	5.55
Esther Cheroitch	Kecheri	5	Sawdust	-	8.42
Esther Cheroitch	Kecheri	5	Tithonia	+	6.28
Esther Cheroitch	Kecheri	5	Tithonia	-	7.51
Esther Cheroitch	Kecheri	5	Control	+	4.29
Esther Cheroitch	Kecheri	5	Control	-	8.62
Esther Cheroitch	Kecheri	5	Farmer Practices	+	7.82
Paul Lidonde	Kapsangere	100	Biochar	+	9.38
Paul Lidonde	Kapsangere	100	Biochar	-	7.71
Paul Lidonde	Kapsangere	100	Sawdust	+	6.88
Paul Lidonde	Kapsangere	100	Sawdust	-	4.34
Paul Lidonde	Kapsangere	100	Tithonia	+	5.45
Paul Lidonde	Kapsangere	100	Tithonia	-	2.72
Paul Lidonde	Kapsangere	100	Control	+	4.77
Paul Lidonde	Kapsangere	100	Control	-	4.44
Paul Lidonde	Kapsangere	100	Farmer Practices	+	2.87
Paul Lidonde	Kapsangere	100	Biochar	-	1.98
Paul Lidonde	Kapsangere	100	Sawdust	-	1.53
Paul Lidonde	Kapsangere	100	Tithonia	+	2.15
Paul Lidonde	Kapsangere	100	Control	+	2.64
Paul Lidonde	Kapsangere	100	Control	-	2.97
Paul Lidonde	Kapsangere	100	Biochar	+	9.02
Paul Lidonde	Kapsangere	100	Sawdust	+	10.42
Paul Lidonde	Kapsangere	100	Tithonia	+	2.38
Solomon Agesa	Kapkerer	90	Biochar	+	5.53
Solomon Agesa	Kapkerer	90	Biochar	-	5.13
Solomon Agesa	Kapkerer	90	Sawdust	+	2.67
Solomon Agesa	Kapkerer	90	Sawdust	-	17.90
Solomon Agesa	Kapkerer	90	Tithonia	+	4.21

Solomon Agesa	Kapkerer	90	Tithonia	-	5.10
Solomon Agesa	Kapkerer	90	Control	+	1.82
Solomon Agesa	Kapkerer	90	Control	-	1.45
Solomon Agesa	Kapkerer	90	Farmer Practices	+	2.59
Solomon Agesa	Kapkerer	90	Biochar	+	3.24
Solomon Agesa	Kapkerer	90	Sawdust	+	3.78
Solomon Agesa	Kapkerer	90	Tithonia	-	3.43
Solomon Agesa	Kapkerer	90	Control	+	13.14
Solomon Agesa	Kapkerer	90	Biochar	-	2.27
Solomon Agesa	Kapkerer	90	Sawdust	-	1.91
Solomon Agesa	Kapkerer	90	Tithonia	+	3.74
Solomon Agesa	Kapkerer	90	Control	-	5.33
Lillian Langat	koibem	10	Biochar	+	2.46
Lillian Langat	koibem	10	Biochar	-	2.36
Lillian Langat	koibem	10	Sawdust	+	4.96
Lillian Langat	koibem	10	Sawdust	-	3.02
Lillian Langat	koibem	10	Tithonia	+	5.25
Lillian Langat	koibem	10	Tithonia	-	1.55
Lillian Langat	koibem	10	Control	+	1.10
Lillian Langat	koibem	10	Control	-	3.01
Lillian Langat	koibem	10	Farmer Practices	+	3.49
Lillian Langat	koibem	10	Biochar	+	2.12
Lillian Langat	koibem	10	Biochar	-	3.37
Lillian Langat	koibem	10	Sawdust	-	2.39
Lillian Langat	koibem	10	Tithonia	+	7.92
Lillian Langat	koibem	10	Tithonia	-	2.65
Lillian Langat	koibem	10	Sawdust	+	3.38
Lillian Langat	koibem	10	Control	+	1.19
Lillian Langat	koibem	10	Control	-	4.32
Herman Magomere	Kiptaruswo	40	Biochar	+	1.14
Herman Magomere	Kiptaruswo	40	Biochar	-	1.67
Herman Magomere	Kiptaruswo	40	Sawdust	+	1.04
Herman Magomere	Kiptaruswo	40	Sawdust	-	0.69
Herman Magomere	Kiptaruswo	40	Tithonia	+	1.12
Herman Magomere	Kiptaruswo	40	Tithonia	-	0.81
Herman Magomere	Kiptaruswo	40	Control	+	1.66
Herman Magomere	Kiptaruswo	40	Control	-	1.18
Herman Magomere	Kiptaruswo	40	Biochar	+	2.30
Herman Magomere	Kiptaruswo	40	Biochar	-	1.78
Herman Magomere	Kiptaruswo	40	Sawdust	+	1.65
Herman Magomere	Kiptaruswo	40	Sawdust	-	1.73
Herman Magomere	Kiptaruswo	40	Tithonia	+	2.75
Herman Magomere	Kiptaruswo	40	Tithonia	-	1.06

Herman Magomere	Kiptaruswo	40	Control	+	10.00
Herman Magomere	Kiptaruswo	40	Control	-	1.18
John Keter	Kechire	10	Biochar	+	1.35
John Keter	Kechire	10	Biochar	-	1.64
John Keter	Kechire	10	Sawdust	+	1.59
John Keter	Kechire	10	Sawdust	-	1.52
John Keter	Kechire	10	Tithonia	+	1.46
John Keter	Kechire	10	Tithonia	-	1.45
John Keter	Kechire	10	Control	+	1.75
John Keter	Kechire	10	Control	-	1.53
John Keter	Kechire	10	Farmer Practices	+	2.81
John Keter	Kechire	10	Biochar	+	1.09
John Keter	Kechire	10	Biochar	-	6.72
John Keter	Kechire	10	Sawdust	+	1.63
John Keter	Kechire	10	Sawdust	-	1.45
John Keter	Kechire	10	Tithonia	+	1.43
John Keter	Kechire	10	Tithonia	-	2.36
John Keter	Kechire	10	Control	+	2.01
John Keter	Kechire	10	Control	-	1.86
Sarah Kutto	Kecheri	10	Biochar	+	0.33
Sarah Kutto	Kecheri	10	Biochar	-	3.83
Sarah Kutto	Kecheri	10	Sawdust	+	2.15
Sarah Kutto	Kecheri	10	Sawdust	-	2.27
Sarah Kutto	Kecheri	10	Tithonia	+	1.99
Sarah Kutto	Kecheri	10	Tithonia	-	1.36
Sarah Kutto	Kecheri	10	Control	+	3.31
Sarah Kutto	Kecheri	10	Control	-	2.42
Sarah Kutto	Kecheri	10	Biochar	+	3.41
Sarah Kutto	Kecheri	10	Biochar	-	3.33
Sarah Kutto	Kecheri	10	Sawdust	+	2.78
Sarah Kutto	Kecheri	10	Sawdust	-	1.33
Sarah Kutto	Kecheri	10	Tithonia	+	1.97
Sarah Kutto	Kecheri	10	Tithonia	-	2.28
Sarah Kutto	Kecheri	10	Control	+	2.51
Sarah Kutto	Kecheri	10	Control	-	2.73
Sarah Kutto	Kecheri	10	Farmer Practices	+	3.39
Japheth Amulele	Kecheri	60	Biochar	+	2.13
Japheth Amulele	Kecheri	60	Biochar	-	3.01
Japheth Amulele	Kecheri	60	Sawdust	+	2.85
Japheth Amulele	Kecheri	60	Sawdust	-	2.42
Japheth Amulele	Kecheri	60	Tithonia	+	1.89
Japheth Amulele	Kecheri	60	Tithonia	-	2.68
Japheth Amulele	Kecheri	60	Control	+	2.26

Japheth Amulele	Kecheri	60	Control	-	1.35
Japheth Amulele	Kecheri	60	Biochar	+	3.73
Japheth Amulele	Kecheri	60	Biochar	-	3.00
Japheth Amulele	Kecheri	60	Sawdust	+	3.19
Japheth Amulele	Kecheri	60	Sawdust	-	2.64
Japheth Amulele	Kecheri	60	Tithonia	+	1.78
Japheth Amulele	Kecheri	60	Tithonia	-	6.32
Japheth Amulele	Kecheri	60	Control	+	6.95
Japheth Amulele	Kecheri	60	Control	-	2.91
Japheth Amulele	Kecheri	60	Farmer Practices	+	3.78
Kipsang Arap Yama	Kecheri	60	Biochar	+	6.24
Kipsang Arap Yama	Kecheri	60	Biochar	-	3.41
Kipsang Arap Yama	Kecheri	60	Sawdust	+	2.36
Kipsang Arap Yama	Kecheri	60	Sawdust	-	1.76
Kipsang Arap Yama	Kecheri	60	Tithonia	+	2.94
Kipsang Arap Yama	Kecheri	60	Tithonia	-	2.73
Kipsang Arap Yama	Kecheri	60	Control	+	3.99
Kipsang Arap Yama	Kecheri	60	Control	-	3.24
Kipsang Arap Yama	Kecheri	60	Farmer Practices	+	5.32
Kipsang Arap Yama	Kecheri	60	Biochar	+	2.46
Kipsang Arap Yama	Kecheri	60	Biochar	-	2.72
Kipsang Arap Yama	Kecheri	60	Sawdust	+	3.45
Kipsang Arap Yama	Kecheri	60	Sawdust	-	3.63
Kipsang Arap Yama	Kecheri	60	Tithonia	+	1.74
Kipsang Arap Yama	Kecheri	60	Tithonia	-	2.63
Kipsang Arap Yama	Kecheri	60	Control	+	1.81
Kipsang Arap Yama	Kecheri	60	Control	-	0.85
Martim Arap Suguti	Siksiket	10	Sawdust	-	1.09
Martim Arap Suguti	Siksiket	10	Tithonia	-	3.68
Bernard Kidiga	Kecheri	60	Biochar	+	3.52
Bernard Kidiga	Kecheri	60	Biochar	-	3.51
Bernard Kidiga	Kecheri	60	Sawdust	+	3.28
Bernard Kidiga	Kecheri	60	Sawdust	-	3.37
Bernard Kidiga	Kecheri	60	Tithonia	+	3.46
Bernard Kidiga	Kecheri	60	Tithonia	-	2.86
Bernard Kidiga	Kecheri	60	Control	+	2.39
Bernard Kidiga	Kecheri	60	Control	-	2.56
Bernard Kidiga	Kecheri	60	Biochar	+	2.56
Bernard Kidiga	Kecheri	60	Sawdust	+	3.66
Bernard Kidiga	Kecheri	60	Sawdust	-	2.62
Bernard Kidiga	Kecheri	60	Tithonia	+	2.07
Bernard Kidiga	Kecheri	60	Tithonia	-	3.13
Bernard Kidiga	Kecheri	60	Control	+	2.37

Bernard Kidiga	Kecheri	60	Control	-	2.39
Bernard Kidiga	Kecheri	60	Farmer Practices	+	2.28
Timothy Chikadi	Kapkerer	80	Tithonia	+	0.13
Timothy Chikadi	Kapkerer	80	Biochar	+	3.69
Timothy Chikadi	Kapkerer	80	Sawdust	+	5.62
Timothy Chikadi	Kapkerer	80	Control	+	4.06
Timothy Chikadi	Kapkerer	80	Tithonia	-	1.24
Timothy Chikadi	Kapkerer	80	Control	-	2.29
Timothy Chikadi	Kapkerer	80	Farmer Practices	+	7.16
Timothy Chikadi	Kapkerer	80	Tithonia	+	41.26
Timothy Chikadi	Kapkerer	80	Biochar	+	11.89
Timothy Chikadi	Kapkerer	80	Sawdust	+	12.36
Timothy Chikadi	Kapkerer	80	Control	+	6.99
Timothy Chikadi	Kapkerer	80	Tithonia	-	6.80
Timothy Chikadi	Kapkerer	80	Biochar	-	2.26
Timothy Chikadi	Kapkerer	80	Sawdust	-	7.81
Timothy Chikadi	Kapkerer	80	Control	-	3.43
Elizabeth Rotich	Kobujoi	10	Tithonia	+	0.18
Elizabeth Rotich	Kobujoi	10	Biochar	+	0.19
Elizabeth Rotich	Kobujoi	10	Sawdust	+	2.14
Elizabeth Rotich	Kobujoi	10	Control	+	1.69
Elizabeth Rotich	Kobujoi	10	Tithonia	-	1.52
Elizabeth Rotich	Kobujoi	10	Biochar	-	0.73
Elizabeth Rotich	Kobujoi	10	Sawdust	-	1.29
Elizabeth Rotich	Kobujoi	10	Control	-	0.87
Philip Tenai	sik sik	20	Tithonia	+	4.55
Philip Tenai	sik sik	20	Biochar	+	1.27
Philip Tenai	sik sik	20	Sawdust	+	3.11
Philip Tenai	sik sik	20	Control	+	3.94
Philip Tenai	sik sik	20	Tithonia	-	2.74
Philip Tenai	sik sik	20	Biochar	-	1.50
Philip Tenai	sik sik	20	Sawdust	-	3.57
Philip Tenai	sik sik	20	Control	-	4.48
Philip Tenai	sik sik	20	Farmer Practices	+	3.20
Philip Tenai	sik sik	20	Biochar	+	3.08
Philip Tenai	sik sik	20	Biochar	-	4.41
Philip Tenai	sik sik	20	Tithonia	+	8.31
Philip Tenai	sik sik	20	Sawdust	+	13.76
Philip Tenai	sik sik	20	Control	+	3.79
Philip Tenai	sik sik	20	Tithonia	-	3.28
Philip Tenai	sik sik	20	Biochar	-	5.44
Philip Tenai	sik sik	20	Sawdust	-	3.00

Julias Songok	Kereri	20	Biochar	+	4.04
Julias Songok	Kereri	20	Sawdust	+	2.95
Julias Songok	Kereri	20	Control	+	5.04
Julias Songok	Kereri	20	Tithonia	-	3.94
Julias Songok	Kereri	20	Sawdust	-	2.15
Julias Songok	Kereri	20	Control	-	4.60
Chebisaas School	Kobujoi	10	Tithonia	+	1.46
Chebisaas School	Kobujoi	10	Biochar	+	3.34
Chebisaas School	Kobujoi	10	Sawdust	+	2.93
Chebisaas School	Kobujoi	10	Control	+	3.42
Chebisaas School	Kobujoi	10	Tithonia	-	2.93
Chebisaas School	Kobujoi	10	Biochar	-	5.39
Chebisaas School	Kobujoi	10	Sawdust	-	5.63
Chebisaas School	Kobujoi	10	Control	-	2.72
Chebisaas School	Kobujoi	10	Farmer Practices	+	0.62
Esther Cheptum	Kobujoi	10	Tithonia	+	3.08
Esther Cheptum	Kobujoi	10	Biochar	+	
Esther Cheptum	Kobujoi	10	Sawdust	+	7.28
Esther Cheptum	Kobujoi	10	Control	+	3.82
Esther Cheptum	Kobujoi	10	Tithonia	-	3.29
Esther Cheptum	Kobujoi	10	Biochar	-	3.54
Esther Cheptum	Kobujoi	10	Sawdust	-	3.09
Esther Cheptum	Kobujoi	10	Control	-	4.18
David Shivachi	Kiptaruswo	40	Tithonia	+	4.56
David Shivachi	Kiptaruswo	40	Biochar	+	10.82
David Shivachi	Kiptaruswo	40	Control	+	8.88
David Shivachi	Kiptaruswo	40	Tithonia	-	2.27
David Shivachi	Kiptaruswo	40	Biochar	-	5.20
David Shivachi	Kiptaruswo	40	Control	-	9.01
David Shivachi	Kiptaruswo	40	Tithonia	+	7.09
David Shivachi	Kiptaruswo	40	Biochar	+	4.84
David Shivachi	Kiptaruswo	40	Sawdust	+	8.17
David Shivachi	Kiptaruswo	40	Control	+	4.61
David Shivachi	Kiptaruswo	40	Tithonia	-	6.00
David Shivachi	Kiptaruswo	40	Biochar	-	5.62
David Shivachi	Kiptaruswo	40	Sawdust	-	5.23
David Shivachi	Kiptaruswo	40	Control	-	12.45
David Shivachi	Kiptaruswo	40	Farmer Practices	+	9.90